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NASA SCOUT

VEHICLES 5 THROUGH 7

REACTION THRUST SYSTEMS
HYDROGEN PEROXIDE

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Prepared:	Checked:	Approved:
J. N. Phillips C. H. Crawford	R. A. Brimmer G. Tarnower W. F. Smith	M. J. Rudick Chief of Space Technology
C. H. Crawford 12-15-61	R. A. Brimmer 12-15-61 W. C. Trent	S. Townsend Manager of Space Technology

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1.0 SUMMARY

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This report describes the Scout hydrogen peroxide reaction thrust system for vehicles No. 5 through 7. The various design problems, including material selection, thermodynamic and fluid flow analysis, and system analysis are discussed.

The basic design of the system is the same as the system developed by Walter Kidde and Company, Incorporated for vehicles No. 1 through 4 except for improved routing of plumbing, changing the 14 pound roll motor thrust reduction system, and deletion of several components.

However, the NASA retrofitted the 20 pound roll motors in the second stage with 40 pound roll motors. This was accomplished after the second stage had been shipped from CVC to Wallops Island launch site. The 40 pound roll motors assured the NASA of better vehicle roll control during the second stage main engine's burning. In accordance with Reference 8.1, no other improvement type changes were made in the two systems. Chance Vought Astronautics feels there are many ways in which the reaction thrust system can be improved to reduce weight, improve both degree and uniformity of performance, and increase reliability if such improvements are feasible from an economic point of view.

Although the present Scout reaction thrust systems are not considered completely refined, they fulfill the essential requirements of both the specification and the vehicle itself. This has been demonstrated by successful functional system tests and in actual vehicle firings.

2.0 INTRODUCTION

The functions of the second and third stage Scout reaction thrust systems are to provide vehicle attitude control and stabilization during main engine operation and vehicle coast. These functions are accomplished by 8 "on-off" reaction thrust motors in the second stage system and 10 "on-off" reaction thrust motors in the third stage system.

3.0 SYSTEM SELECTION

The use of 90 percent hydrogen peroxide (H_2O_2) as the propellant for the second and third stage reaction thrust systems was specified by Minneapolis-Honeywell for Scout vehicles No. 1 through 4. The hydrogen peroxide reaction thrust system adequately fulfills the Scout second and third stage control requirements; therefore, it was retained by Chance Vought Astronautics Division for vehicles 5 through 7.

The use of conventional aerodynamic control surfaces such as those utilized in the first stage of the vehicle is not practical for second and third stage control since these controls are required to operate beyond the earth's sensible atmosphere (above 130,000 feet). The need for control during coast periods subsequent to burnout of the main rocket engine precluded the use of deflectors in the main engine exhaust stream or other such schemes which are effective only during burning of the main engine. Therefore, a reaction thrust system utilizing gaseous products was indicated for the second and third stage control systems.

There are five basic types of reaction control systems that could be considered for the Scout application. The general characteristics for each are listed.

REACTION CONTROL SYSTEMS

Type	Specific Impulse Range	Applicable Impulse Range	Coast Time	Complexity	Reliability Potential	Restart Capability
Cold Gas	Low	Low	Limited-Long	Low	Excellent	Yes
Monopropellant	Medium	Med-High	Indefinite	Medium	Excellent-Good	Yes
Bi-Propellant	Med-High	High	Indefinite	High	Good-Fair	Yes
Solid Engines	Med-High	Medium	Limited	Med-High	Good	No
Hot Gas	Med-High	Medium	Limited	High-Med	Fair	No

To best fulfill the requirements for Scout, a bi-propellant system should be used in "B" section and a mono-propellant in "C" section, but on the basis of simplifying vehicle maintenance, logistics, and system development, it was decided to use a mono-propellant for both stages.

The three mono-propellants considered for this application were hydrogen-peroxide, hydrazine, and ethylene oxide. The important characteristics of these propellants are shown below.

MONO-PROPELLANTS

Type	I_{SP} 300-14.7 psi	Density at 68°F #/Ft^3	Decomp. Temp. °F at 68°F Fuel Temp.	Freezing Temp. °F	Catalyst Repeated Starts	Toxicity
Hydrogen-Peroxide 90%	132	86.7	1360	11.3	Silver	Burnt skin
Hydrazine	162	62.6	1565	34.5	Heat source	Toxic
Ethylene Oxide	169	54.4	1728	-170.4	Heat source	Low

Ninety (90) percent hydrogen peroxide was chosen because it required no external energy for starting, was readily available, fairly inexpensive, relatively easy to handle, has a good storage life when handled correctly, and has a low combustion temperature. These advantages outweighed the better performance of the other two mono-propellants considered.

Gaseous nitrogen was chosen for the pressurizing medium because of the availability of hardware that could be used with it, and the vast amount of experience that has been built upon its use.

4.0 SYSTEM DESCRIPTION

Restoring moments for desired vehicle orientation are provided by 8 pressure fed "on-off" reaction thrust motors in the second stage system and 10 pressure fed "on-off" reaction thrust motors in the third stage system. These motors are so placed that moments are set up about each of the 3 axes, pitch, roll, and yaw. The motors are mono-propellant and utilize 90 percent hydrogen peroxide (H_2O_2). Propellant pressurization is provided by a compressed nitrogen (N_2) gas system

A schematic diagram and weight breakdown of the second and third stage systems are presented in Figures 1 and 2 and Table I, respectively.

5.0 SYSTEM OPERATION

The following operational description applies to both the second and third stage reaction thrust systems.

Referring to either Figure 1 or 2, the system is charged with hydrogen peroxide through the peroxide charging valve. The peroxide entering the system fills the lines and rises into the peroxide tanks. The peroxide enters the tanks through the expulsion tubes and continues to rise vertically within the tank bladders. Any air and/or gas which may be present in the tanks is displaced by the entering peroxide and vented overboard through the peroxide tanks' overboard drain tube, the overboard drain line, the 10 psi back pressure check valve (installed to insure complete filling of the bladder with peroxide), and the system bleed valve. When the peroxide level reaches the top of the peroxide tanks' overboard drain tubes, peroxide begins flowing through the bleed system indicating that the system is fully charged. The overboard tubes are located so as to provide sufficient ullage within the tanks to allow for expansion of peroxide due to an increase in temperature.

The nitrogen system is charged by means of the nitrogen charging valve. Through this valve, nitrogen enters the storage tanks and the line leading to the nitrogen shut-off or pressurization control valve. Charging continues until the nitrogen pressure is brought up to the system rated pressure (3000 psia for the second stage at 70°F and 1000 psia for the third stage at 70°F). The system is now ready for operation except for pressurizing the hydrogen peroxide system. This is accomplished by opening the nitrogen solenoid shut-off valve which allows regulated nitrogen (525 psia for the second stage system and 455 psia for the third stage system in the locked up condition) to flow through the nitrogen manifold to the gas side of the bladders in the peroxide tanks. This pressurizes the peroxide in the tanks and lines up to the inlet of the reaction thrust motor control valves.

All motor valves are direct "on-off", solenoid operated valves except for the 500 pound motor valves which are solenoid controlled and pneumatically actuated. The direct solenoid operated valves are opened upon receipt of a signal from the guidance package. Hydrogen peroxide under pressure passes from the tanks through the expulsion tubes, peroxide lines, and motor control valves, distributed over the decomposition chambers' silver screen catalyst beds and decomposes into superheated steam and oxygen. The hot gaseous products expand through a convergent-divergent nozzle and produce a reactive thrust. This process continues until the thrust produced by the motors has satisfied the trajectory correction requirements for the vehicle. After the necessary correction has been effected, the guidance package will interrupt the signal to the peroxide control valve, thus closing the valve and interrupting the flow of the peroxide.

When an electrical signal from the guidance is applied to the 500 pound motor valve, the solenoid closes the regulated supply line and vents the trapped nitrogen within the valve overboard, allowing the fuel inlet pressure to open the valve and permit peroxide to flow to the motor. Removal of the electrical signal from the valve pressurizes the back side of the valve shuttle which closes the valve.

The third stage 14 pound roll motor thrust is reduced to 3 pounds during the coast phase of the vehicle flight to conserve peroxide. This is accomplished by placing a normally-closed solenoid valve in line with the 14 pound roll motor and placing an orificed by-pass line in parallel with the valve. At the cessation of burning of the third stage engine, the vehicle timer de-energizes the in-series solenoid valve, allowing the valve to close. Therefore, peroxide to the roll motors is forced to pass through the orificed by-pass line. The orifice is sized (0.014 inches nominal diameter) so as to produce a significant loss in peroxide pressure (approximately 350 psi). This reduced fuel pressure to the roll motors (approximately 75 psi) yields a lower motor chamber pressure, resulting in a lower thrust level (3 pounds). This thrust is adequate to overcome any small roll moment induced by the firing of the small pitch (2 pounds) and/or yaw (3 pounds) control motors.

During the coast phase of the third stage, the roll motors (3 pounds) also satisfy the yaw correction requirements. The small pitch motors (2 pounds) are used during coast and are adequate for any pitch correction necessary.

6.0 SYSTEM DESIGN REQUIREMENTS

The design objective was to provide a reaction thrust system capable of producing a given total impulse with reaction control motors of stated thrust levels. This objective was to be obtained utilizing a minimum weight and envelope within the limitations of the system requirements. The major design requirements are summarized in Table II.

7.0 SYSTEM DESIGN ANALYSIS

7.1 Effect of Nozzle Configuration on System Performance

In order to establish data for the theoretical performance of the second and third stage reaction motors for the ambient pressures specified in Table II, the reaction chamber pressure was estimated. The actual operating chamber pressure is limited not only by the pressurizing system pressure limitations, but by considerations of the reaction chamber weight and strength at the maximum feed temperature. The hydrogen peroxide feed temperature range of 40°F to 160°F as specified in Table II corresponds to a reaction temperature range of 1320°F to 1510°F. Thus, the reaction chamber must have sufficient strength to contain decomposition gases having a maximum temperature of approximately 1500°F.

Making allowance for pressure losses due to the flow of hydrogen peroxide through the feed lines, control valve, and catalyst pack a maximum chamber pressure of 300 psia was chosen. The actual selection of optimum chamber pressure for the motors in both stages would require an extensive parametric analysis of the system which was not attempted. Rather, the motor chamber pressure was selected based upon using a high enough pressure to keep the motor nozzle size within acceptable limits, and yet provide a tolerable utilization factor for the pressurant gas. The selected maximum chamber pressure of 300 psia appeared to be a reasonable design compromise in view of these design limitations.

Having chosen the chamber pressure, the theoretical performance of various nozzle geometries was investigated. For this investigation the properties of 90 percent hydrogen peroxide at a feed temperature of 65°F was used. The corresponding reaction temperature is 1360°F, and the specific heat ratio is 1.264 at the estimated chamber pressure of 300 psia. Although the reaction temperature of 1360°F is somewhat higher than the minimum reaction temperature of 1320°F, the effect on calculated motor performance is slight. Theoretical performance curves are given in Figures 3 through 7. Figure 3 is a plot of Nozzle Area Ratio versus Pressure Ratio for a specific heat ratio of 1.264 and is given to facilitate translation of area ratios into pressure ratios. Figure 4 presents the maximum specific impulse of 90 percent hydrogen peroxide at a feed temperature of 65°F for optimum expansion, i.e., the nozzle exit pressure is equal to ambient pressure. Figure 5 shows the effects of over or under expansion on the maximum specific impulse at optimum expansion ratios as shown on Figure 4. The ratio of the specific impulse of Figure 4 to the specific impulse for an actual nozzle configuration is plotted against nozzle pressure ratio (Pc/Pe) as a function of the ambient pressure ratio (Pc/Pa). The theoretical performance of all possible second and third stage rocket motors at the respective design conditions is obtained from the data given in Figures 4 and 5. This performance is plotted in Figure 6 as Actual Theoretical Specific Impulse versus Nozzle Pressure Ratio for the values of ambient pressures specified as design conditions for second and third stage reaction motors. Figure 7 is a plot of Altitude to Sea Level Specific Impulse Ratios versus Nozzle Pressure Ratio and was developed from the data in Figures 4 and 5. The nozzle dimensions for all second and third stage motors are given in Figure 8 and are the basis of the tabulated data given on motor performance in Figures 9 and 10.

Figure 9 presents the theoretical motor performance data upon which the system was designed by Walter Kidde Co. and Figure 10 presents the performance based on test data of the actual components. The motor chamber pressure (Pc) values in Figure 9 were based on a nozzle efficiency of 100 percent while those in Figure 10 were obtained by determining the correct sea level thrust corresponding to a given altitude thrust from Figures 11 through 15 and 21 and then reading the correct chamber pressure from Figures 16 through 20 and 22. The Sea Level versus Altitude Correction Curves (Figures 11 through 15 and 21) are based on motor test data obtained in a vacuum chamber and at sea level, and the Sea Level Thrust versus Chamber Pressure Curves (Figures 16 through 20 and 22) are averages for each motor based on test data obtained during the original NASA and Air Force 609a programs. A wide variation in motor performance was obtained, and these curves should be used with caution. The nozzle and pressure ratio information presented in Figures 9 and 10 were obtained from Figures 3 and 8. The actual thrust coefficient (C_f) given in Figure 10 was calculated from the relation $C_f = \frac{F}{A_t \, P_c}$.

The theoretical C_f at the design ambient pressure (P_a) came from the Ramo-Wooldridge Tables for a $\gamma = 1.264$, and the nozzle efficiency (η_n) is the ratio of these two values. The specific impulse (I_s) in Figure 9 was taken from Figure 6, and the fuel flow rate ($\dot{w}$) was calculated from the formula $\dot{w} = \frac{F}{I_s}$. The specific impulse in Figure 10 was based on average values obtained by testing No. 5 vehicle motors. The silver screen catalyst area was obtained from Walter Kidde data, and the catalyst loading factor is based on that area. It should be noted that the actual loading factor for the second stage motors is well over the recommended value of 20 pounds per minute per square inch which is a result of uprating the motors.

7.2 Tankage

7.2.1 Hydrogen Peroxide

The required hydrogen peroxide storage capacity was determined by estimating the actual performance of the reaction motors. Since all the reaction motor nozzles have an ideal specific impulse range of 158-164 seconds, a mean value of 160 seconds was used as a basis for determining hydrogen peroxide tankage capacity. Assuming a nozzle efficiency of 90 percent, the actual specific impulse of hydrogen peroxide is 144 lb-sec/lb., which agrees quite well with the test data noted in Figure 10. The hydrogen peroxide capacity required for the second and third stage steady state total impulse (Table II) is therefore 178 and 17.8 pounds, respectively. The expulsion efficiency of the bladder type peroxide tanks is approximately 99 percent, but, the fuel in the manifold and lines is not usable. This amounts to about 2.5 to 3 pounds in "B" section and 1 pound in "C" section or a fuel unavailability per section of 2.5 and 6.25 percent, respectively. With the state required quantities of 178 and 17.8 pounds of hydrogen peroxide for the second and third stage systems respectively, the specific impulse that must be obtained to provide the total impulse for cyclic operation is calculated to be 117 and 123 seconds for the second and third stages, respectively. Thus, the specification allows considerable degradation of reaction motor performance when operated intermittently as compared to continuous operation.

The required volume of the hydrogen peroxide tanks was determined by the density of hydrogen peroxide and the total weight of peroxide carried by each stage. For a density of 86.9 pounds per cubic foot, the required values are 3640 and 364 cubic inches for the second and third stages, respectively, based on the usable volume of peroxide. The calculations, which determine the capacity of the hydrogen peroxide tankage, are summarized in Table III.

7.2.2 Nitrogen

The nitrogen fuel pressurization systems for the second and third stage reaction control systems are based on the nominal hydrogen peroxide tankage volumes plus the volume of the lines and fittings. The nitrogen storage capacity depends on the amount of heat transfer to the nitrogen during operation as well as system pressures and fuel tank volumes. The extremes are given by isothermal and adiabatic expansion of the nitrogen. The actual system operates somewhere between these extremes.

The nitrogen storage capacities required for isothermal and adiabatic pressurization of the fuel tanks is given by the following expressions:

$$(V_{N_2})_{min} = V_{H_2O_2} \frac{P_p}{P_i - P_f} \qquad \text{Isothermal}$$

$$(V_{N_2})_{max} = \gamma \, V_{H_2O_2} \frac{P_p}{P_i - P_f} \qquad \text{Adiabatic}$$

where: V_{N_2} = volume of nitrogen storage tank

$V_{H_2O_2}$ = volume of hydrogen peroxide storage tanks

γ = specific heat ratio for nitrogen

P_p = fuel pressure (psia)

P_i = initial nitrogen container pressure

P_f = final nitrogen container pressure

Assuming a minimum pressure drop across the pressure regulators of 50 psi, and using the fuel system pressures of 525 psia for the second stage and 455 psia for the third stage, the maximum and mininum values of nitrogen storage capacity for each stage are as follows:

	Second Stage	Third Stage
Hydrogen Peroxide Tankage Volume - Cu. In.	4,000	400
P_i (psia)	3,000	1,000
P_f (psia)	550	490
P_p (psia)	525	455
$(V_{N_2})_{min}$ (Cu. In.)	816	321
$(V_{N_2})_{max}$ (Cu. In.)	1,140	450
Actual V_{N_2} (Cu. In.)	780	390

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Note that the actual nitrogen volume for the second stage tankage is less than that required even considering isothermal expansion. This tankage was designed by Walter Kidde Co. for the NASA 1 through 4 and the Air Force 609a vehicles, and the following is their justification for under designing the tankage. "It would at first appear that the supply is therefore inadequate for the application. However, it must be further considered that such a condition will merely result in the reduction of fuel supply pressure toward the end of the system cycle provided the demand has been fairly high and virtually all of the peroxide on board has been utilized. This will result in lower motor thrust levels toward the end of the cycle which actually will be sufficient to control the vehicle (reference low thrust level requirements for Scout 1 through 4 and 609a vehicles) and in effect will reduce system fuel consumption. The reduced nitrogen volume can thus be expected to have a beneficial effect on system performance." Since the system has performed satisfactorily thus far, no attempt was made to increase the weight of nitrogen stored in the second stage for vehicles 5 through 7.

7.3 Lines, Valves and Fittings

7.3.1 Basis for Selection of Line, Valve and Fitting Sizes

The selection of line, valve and fitting sizes was based on the expected maximum hydrogen peroxide or nitrogen flow rates at various points in the system. The individual motor flow requirements used for design by Walter Kidde are shown on Figure 9. All of the hydrogen peroxide lines were sized for a maximum flow velocity of 20 feet per second. The pressure losses per foot of line and the flow rate at this velocity are given below.

HYDROGEN PEROXIDE LINES

Nominal Size	Tube ID	Peroxide Density #/Ft3	Velocity Ft/Sec.	Flow Rate #/Sec.	Pressure Drop ΔP psi/ft.
1/4	0.180	86.9	20	0.308	5.83
3/8	0.305			0.881	3.03
1/2	0.430			1.76	1.95
5/8	0.555			2.97	1.45
3/4	0.680			4.38	1.11
7/8	0.805			6.25	0.90
1	0.930			8.20	0.75
1-1/4	1.180	86.9	20	13.20	0.556

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The gaseous nitrogen lines were also sized to obtain a small pressure drop for the maximum flow rates expected in each system. The following table gives the pressure drop in psi per foot of length for three line sizes and flow rates of 10, 50, and 100 percent of the maximum expected design flow rate of 0.213 pounds per second and the maximum expected actual flow rate of 0.248 pounds per second.

NITROGEN LINES

Flow Rate - #/Sec		Pressure Drop - ΔP - psi/ft.					
		1/4"-ID = .180"		3/8"-ID = .305"		1/2"-ID = .430"	
Design	Actual	Design	Actual	Design	Actual	Design	Actual
0.0213	0.0248	0.48	0.90	0.045	0.074	----	----
0.107	0.124	9.2	17.7	0.83	1.35	0.17	0.254
0.213	0.248	----	----	2.9	4.6	0.60	0.87

Fittings and valves were generally chosen in accordance with the line sizes in both the fuel and pressurization systems.

7.3.2 Second Stage

The line sizes for the peroxide system were sized by Walter Kidde based on the information in Figure 9. These same line sizes were used in vehicles 5 through 7 since detail design data was not available to CVC in time to check the Kidde design. The actual flow rates that may be expected based on measured specific impulses and nominal and maximum thrust levels are higher than Kidde's design values. The following table presents a comparison of the design with actual conditions. The line sizes were obtained from the table in Section 7.3.1 based on the fuel flow.

HYDROGEN PEROXIDE
FLOW RATES AND LINE SIZES

	Vehicle	W-K Design		Nom. Thrust		Max. Thrust	
	Line Size In.	Flow Rate #/Sec	Line Size In.	Flow Rate #/Sec	Line Size In.	Flow Rate #/Sec	Line Size In.
500# Motor Line	3/4	3.58	3/4	4.28	3/4	4.67	3/4
20# Motor Line	3/8	0.144	1/4	0.163	1/4	0.196	1/4
40# Roll Motor Line	3/8	----	--	0.364	3/8	0.40	3/8
Manifold	1.0	7.5	1.0	8.9	1.0	9.73	1-1/8
Tank Feed Lines (10 tanks)	3/8	0.75	3/8	0.89	3/8	0.97	1/2
Fill Line	3/8	---	3/8	----	---	---	---
Bleed Line	1/4	---	1/4	----	---	---	---

Only in the case of the main manifold are the vehicle lines too small to carry the nominal flow rate at velocities less than 20 feet per second. Under maximum flow conditions all the lines are slightly undersized except for the 20 pound motor line which was chosen over sized for handling reasons. In none of these cases will the velocity in the lines exceed 22-25 feet per second and a change in size would not be justified.

Assuming that each of the ten storage tanks feed the main manifold uniformly the chosen line size is marginally adequate.

The sizing of the fuel fill and vent lines was based on the charging flow rates. Since the system can be charged in approximately 15 minutes at a fueling pressure of 50 psi, the chosen 3/8 inch fill line and 1/4 inch vent line up to the back pressure relief valve are considered adequate.

The nitrogen line sizes were also selected by Walter Kidde based on the fuel flows noted in Figure 9 and above. The density of the nitrogen gas pressurizing the fuel tanks was assumed to be 2.50 pounds per cubic foot at 500 psia and 70°F. Since, for a given mass flow density (i.e., fixed mass flow rate and pipe diameter), the pressure loss is inversely proportional to the density, all the nitrogen lines were sized for the lowest density in the system (2.50 lbs/ft^3). The following table presents a comparison between the design and nominal thrust conditions. The line pressure losses were obtained from the table shown in Section 7.3.1.

NITROGEN
FLOW RATES AND LINE PRESSURE LOSS

	Vehicle Line Size In.	W-K Design Flow Rates #/Sec.	W-K Design Line ΔP psi/ft.	Nominal Thrust Flow Rates #/Sec.	Nominal Thrust Line ΔP psi/ft.
N_2 Manifold	1/2	0.213	0.60	0.248	0.87
N_2 Feed Line to Manifold	1/2	0.107	0.17	0.124	0.254
N_2 Feed Line to H_2O_2 Tanks	1/4	0.0213	0.48	0.0248	0.90

It will be noted that the line loss associated with the nominal thrust flow rates are higher than the design values but are still quite low. For this reason no thought has been given to increasing the size of the nitrogen lines.

The nitrogen supply lines to the 500 pound motor valves' pilot are 1/4 inch. Since essentially no flow occurs in these lines, a smaller line could be used, but for practical considerations it was not considered wise to go below 1/4 inch.

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7.3.3 Third Stage

The peroxide line sizes in the third stage were also selected by Walter Kidde in a similar manner to the second stage selection. The following table presents a comparison of the design and actual conditions. The line sizes were obtained from the table in Section 7.3.1 based on the fuel flow.

HYDROGEN PEROXIDE
FLOW RATES AND LINE SIZES

	Vehicle Line Size In.	W-K Design		Nom. Thrust		Max. Thrust	
		Flow Rate #/Sec	Line Size In.	Flow Rate #/Sec	Line Size In.	Flow Rate #/Sec	Line Size In.
40# Motor Line	3/8	0.274	1/4	0.364	3/8	0.40	3/8
Cluster Line*	3/8	0.359	3/8	0.453	3/8	0.497	3/8
Manifold	3/8	0.718	3/8	0.905	3/8	0.995	1/2
Tank Feed Lines (2 Tanks)	3/8	0.359	3/8	0.453	3/8	0.497	3/8
Fill Line	3/8	------	3/8	------	---	------	---
Bleed Line	1/4	------	1/4	------	---	------	---

*A cluster consists of one 40 pound motor, two 14 pound motors, and one 2 pound motor feed from the same feed line.

It will be noted that the manifold is marginal under the maximum thrust conditions, but here again the expected velocities would be less than 25 feet per second and larger lines not justified.

Since the third stage fuel flow is about one-tenth of the second stage flow rate (0.960 lbs/sec. vs. 8.9 lbs/sec.) the nitrogen flow rate for the third stage is approximately one-tenth that of the second stage. It will be noted from the table in Section 7.3.2 that the maximum pressure loss in a 1/4 inch line would be 0.90 psi per foot. Therefore, the 1/4 inch line was chosen for all the nitrogen lines in the third stage system since smaller lines were not considered practical.

7.4 Pressure Reducers, Relief Valves, and Solenoid Control Valves

7.4.1 Pressure Reducer, W.K. P/N 3593C-0002

This pressure reducer is employed in the second stage reaction control system. It is a high quality aircraft type pressure reducer which is capable of operating with an upstream pressure in the range of 3000 to 500 psi. The delivery pressure is adjustable to any desired value within a wide range. In this application, the delivery pressure is set at a nominal value of 525 psi. The reducer has a rated capacity flow factor of 0.48.

The design incorporates a balancing device which permits large variations of upstream pressure without seriously affecting the delivery pressure. This device acts to overcome the effects of both upstream and downstream pressure variations by equalizing the forces within the reducer. A delivery pressure sensing piston acts against a spring to control the delivery pressure without extraneous forces affecting the control.

This particular pressure reducer design has been successfully employed by Walter Kidde & Co. since 1953, and has passed the qualification tests of Specification MIL-R-8572A.

7.4.2 Pressure Reducer, W.K. P/N 2172E-0212

This pressure reducer is used in the third stage reaction control system and was designed specifically for the small envelope requirements. These pressure reducers are now being made in quantity and have undergone functional and acceptance testing. As in the second stage reducers, this design features a balancing device which allows appreciable variations of upstream pressure (1100 psi to 500 psi) without significant effect on the delivery pressure which is set for a nominal value of 455 psi. The rated capacity flow factor for this reducer is 0.05.

Effects of both upstream and downstream pressure variations are overcome by the internal balancing of pressure forces in the reducer. A spring loaded pressure sensing piston controls the delivery pressure and its design is such that control is not affected by extraneous forces.

7.4.3 Nitrogen Relief Valve, W.K. P/N 872798-0525

This nitrogen pressure relief valve, which is used in both the second and third stage system, has been in production at Walter Kidde & Co. for some time. It has been tested in accordance with Grumman Aircraft Engineering Corp. specifications, and is used extensively in pneumatic systems.

The valve is a direct acting type which permits a small compact envelope compared to other designs that use larger pressure sensing areas. The seat or dynamic seal finds wide usage in many Walter Kidde's valves and has shown good reliability for pneumatic operation up to 2500 psi. A unique feature of this relief valve is that it permits extremely high relief flows when the relief pressure slightly exceeds the normal rated flow pressure. The set or cracking pressure for this relief valve is 650 ± 20 psi.

7.4.4 Relief and Bleed Valve Assembly, W.K. P/N 3593B-0022 and 3593B-0012

The relief and bleed valve assembly is used in both the second (3593B-0022) and third stage (3593B-0012) reaction control systems. It is an in-line assembly used to allow overboard hydrogen peroxide pressure relief in case of over-pressurization of the system.

This assembly incorporates a 10 psi valve (W.K. P/N 2169E-0002), an AN 938-4 tee and a 700 psi relief valve (second stage) and 600 psi relief valve (third stage). The design of the relief valve is similar to the nitrogen relief valve (872798-0525) except for the use of a different "O"-ring material compatible with 90 percent hydrogen peroxide. This relief valve permits satisfactory relief flows when the valve inlet pressure slightly exceeds the pressure to produce rated flow. The cracking pressure is 700 psi (second stage) and 600 psi (third stage) and the reseat pressure is 10 percent below cracking pressure. The 10 psi valve has a cracking pressure of 14-18 psi and a reseat pressure of 5 psi minimum and is used to maintain pressure on the peroxide system during fueling. The AN 938-4 tee accommodates a Koehler (3-110634) "on-off" bleed valve.

7.4.5 Solenoid Operated Fuel Control Valve, Co-Axial Unbalanced, W.K. P/N 2172C-0003

This valve is used to control the flow of fuel to the 2 pound thrust motor. It is a simple and compact design requiring low power for operation. The spool and the shell of the valve are pressure tight. When the solenoid coil is energized, the armature moves and permits axial flow through the slots and drilled flow passages. Upon de-energization of the coil, a spring forces the armature against the valve poppet which thereupon closes against the seat, stopping the flow of fuel. Consideration was given in the design of this valve to the proper selection of materials so that all surfaces in contact with the fuel are fully compatible with it.

7.4.6 Solenoid Operated Fuel Control Valve, Co-Axial Balanced, W.K. P/N 3593D-0013, 3593D-0023, or 3593D-0003

These valves are used to control the flow of hydrogen peroxide to the 14, 20, 40 pound roll and 40 pound pitch and yaw thrust motors. Essentially, the three valves are identical except for attaching fittings and flanges. The solenoid of this valve has an armature which is designed to permit free flow of fuel axially through the valve assembly. An extended stem on the armature acts as a valve seat and also serves as a balancing piston. A drilled passage through this stem permits upstream pressure to act over the cross-sectional area of a cylindrical cavity thereby producing a force equal to and opposite the pressure force acting on the valve seat. This balancing feature makes it possible to employ larger seat diameters and higher pressures with a given solenoid. Within the solenoid coil load capacity, flow can be varied by changing the valve travel, and in effect, this is what is done to utilize the same basic valve for three different motors.

Again, all the valve materials have been carefully selected for compatibility with the fuel.

7.4.7 Motor Control Valve, Marotta Type MV-159DB, P/N 218894

This "on-off" type valve is used to control the flow of fuel to each of the 500 pound thrust motors in the second stage reaction control system. It is capable of delivering 4.65 pounds per second of hydrogen peroxide with a maximum pressure drop of 20 psi while operating over the range of system pressures.

Functionally, the valve requires a source of clean dry nitrogen whose pressure is equal to that of the hydrogen peroxide at the inlet. The nitrogen enters at the valve pilot section and pressurizes the back side of the fuel shuttle assembly. Since the shuttle area exposed to the nitrogen is larger than that acted on by the fuel pressure, a differential force exists which insures positive closing. To prevent the valve from opening when the system is being charged with fuel and there is, as yet no nitrogen pressure on the pilot side of the shuttle, a helper spring is incorporated in the design. This spring exerts a force on the shuttle which is sufficient to keep the valve closed until the fuel pressure exceeds 35 psi.

Energization of the valve solenoid with a voltage of 24-30V DC results in shutting off the nitrogen supply into the valve and venting of the nitrogen side of the shuttle to atmosphere. The valve opening and closing response characteristics exceed the specified requirements and are marginal if long coast times are required for the second stage.

7.4.8 Solenoid Operated Thrust Control Valve, Marotta Type MV 100T

This valve is used to force the flow of peroxide to the 14 pound roll motors through an orificed by-pass line during the coast phase of the vehicle flight. It is a simple and compact design requiring low power (1 ampere) for operation. When the solenoid coil is energized, the armature moves and permits flow through the valve. Upon de-energization of the coil, a spring forces the armature against the valve poppet which thereupon closes against the seat, shutting off the flow of peroxide. All materials of the valve that are in contact with peroxide are fully compatible.

7.4.9 Nitrogen Solenoid Latching Valves, W.K. P/N 3593H-0014 and 3593H-0004

This valve is used to remotely pressurize and depressurize the hydrogen peroxide system and replaces the squib valve used on the first Scout and 609A vehicles. The two solenoids used for opening and latching require a maximum current of 1 ampere apiece.

The materials used in the valves are not specifically for peroxide use, but the downstream side of the valve is stability checked and any excessive activity is cause for rejection.

A pulse current of the main solenoid allows regulated nitrogen to by pass and pressurize the downstream side of the primary shuttle which is spring loaded closed. This pressure exerts a force sufficient to overcome the spring and opens the valve. When the main solenoid is pulsed, the spring loaded latching solenoid locks it in the open position. To close the valve a pulse current is applied to the latching solenoid causing its piston to be withdrawn from the detent in the main solenoid shaft, thereby allowing it to close. The regulated nitrogen holding the primary shuttle open is then bled overboard and the primary shuttle spring closes the main valve. The pressurizing gas in the peroxide system is vented overboard through a restricted passage equivalent to an 0.030 inch diameter orifice.

7.4.10 Charging Valve, W.K. P/N 2169B-0023 and 3593B-0002

This charging valve is used in conjunction with charging the second (2169B-0023) and third (3593B-0002) stage reaction thrust systems with 90 percent hydrogen peroxide. The charging valve is a needle type valve with a metal to metal seat and is manually operated.

7.5 Selection of Materials

The selection of materials for the second and third stage reaction control systems has been based on two considerations. First, selection was made on the basis of strength to weight ratios which were most compatible with the requirements of the flight components. The second and major factor, since it could not be comprized even to save weight, was that only compatible materials could be used for those parts which were to be in contact with the hydrogen peroxide. These two considerations determined the material selections which were made for the various parts of the systems and are discussed in the following paragraphs.

7.5.1 Nitrogen Storage Tanks

The nitrogen storage tanks in both the second and third stage systems have been fabricated of SAE 4130 alloy steel and are coated with an epoxy resin on the inside. This material was selected because of its high strength properties and its ease of fabrication for the type of pressure vessel under consideration. SAE 4130 alloy steel is not an optimum material for this application when compared to titanium or some of the other more exotic high strength materials. However, the weight saving which could be realized by using one of these materials would be fairly small. Fabrication would be more difficult, and result in higher costs. Hence, SAE 4130 steel was the choice for the nitrogen storage tanks.

7.5.2 Fuel Tanks

Pure aluminum is the most compatible material with hydrogen peroxide. However, since it is a poor material from the standpoint of strength, a severe weight penalty would be incurred if it were used. Since a bladder was to be used to separate the stored fuel from the tank walls, the need for making an optimum aluminum selection in regard to compatibility was not of primary importance. Therefore 6061-T6 aluminum alloy was selected for the hydrogen peroxide storage tanks. This material is Class 2 when properly treated in accordance with NAVAER 06-25-501 and has excellent strength properties. Forming of 6061-T6 is relatively simple and economical, while welding and brazing present no particular problems. Other minor parts of the fuel tank assembly were also made of 6061-T6 aluminum alloy.

Insofar as the bladder was concerned, the first material considered was Teflon. At the time when material selections were being made it appeared that making the bladder out of Teflon would result in an extremely high cost for this item. Mainly because of this cost factor, other possible bladder materials were investigated, and Silastic 9711 was found to be a suitable choice and is currently used for the bladders of the fuel tanks.

7.5.3 Lines

7.5.3.1 Second Stage

The high pressure nitrogen lines in the second stage are fabricated from 321 stainless steel tubing, because of its high strength properties. The higher strength was required to withstand the pressures employed on the second stage system without going to extremely thick walled aluminum tubing. These lines are 1/2 inch diameter from the tanks to the manifold inclusive and are 1/4 inch from the manifold to each hydrogen peroxide tank.

With regard to the peroxide lines in the second stage system, the material selection was stainless steel with the exception of the flexible hoses which are made of stainless steel-teflon lines. Stainless steel was chosen rather than aluminum due to the possibility of aluminum hydroxide formation in aluminum lines. During the course of system development, some experimentation was carried out in an effort to find suitable means of protecting aluminum tubing against the formation of aluminum hydroxide. Treatment with various acids and other solutions as well as sulfuric acid anodization were studied. At first, anodization appeared to be satisfactory, but when this was tried on several systems the formation of aluminum hydroxide was found to be quite pronounced, even to the extent of possible clogging the lines and/or the valves in the system. To obtain satisfactory anodization special tooling would be required with a corresponding increase in cost. Consequently, this approach was abandoned and 316 stainless steel tubing and Teflon flexible hose are currently used in the second stage hydrogen peroxide system.

7.5.3.2 Third Stage

Much of the discussion dealing with the second stage lines is applicable to the third stage system. The fuel and nitrogen lines are fabricated from 321 stainless steel tubing. In this stage, the storage pressure of the nitrogen is only 1000 psi maximum, and the high pressure supply line is 1/4 inch diameter.

7.5.4 Fittings

In the case of aluminum AN fittings, the material of fabrication is 6061 aluminum alloy. With regard to the stainless steel fittings, those used in the subject systems are specified as "S" type AN fittings. This means that they must be made of either Type 304L or Type 347 stainless, rather than Type 303 stainless which is not very compatible with hydrogen peroxide.

7.5.5 Pressure Reducers

The pressure reducers for the second and third stage systems are 2024-T4 aluminum alloy body with synthetic rubber and nylon seals or seats. Some of the internal metallic parts are 303 stainless steel and the spring is tin plated spring steel.

7.5.6 Check Valves

Stainless steel (304), compatible with hydrogen peroxide, has been used in the systems' check valves. These valves were located in the nitrogen supply lines just downstream of the pressure reducers to guard against the remote possibility of peroxide getting into the nitrogen lines and flowing back into the pressure reducers. Since the incorporation of the nitrogen latching valve there is no requirement for these valves. It has been retained because the system procurement and fabrication were too far along to economically remove it.

7.5.7 Relief Valve and Bleed Assembly

These assemblies consist of 700 psi (second stage) and 600 psi (third stage) relief valves, 10 psi check valves and AN 938-4 tees. The 700 and 600 psi relief valves are 6061 aluminum which are sulfuric acid anodized for peroxide compatibility. The 10 psi check valves are 304 stainless steel and the AN 938-4 tees are corrosion resistant steel compatible with hydrogen peroxide for Class 2 service.

7.5.8 Reaction Motor Control Valves

The detail parts of the Walter Kidde reaction motor control valves in contact with hydrogen peroxide are fabricated from 304 stainless steel except for the plungers which are 17-4 PH stainless steel. This was chosen for its magnetic properties and is a Class 2 material.

The valve used for the 500 pound thrust motor is fabricated from 6061-T aluminum. This valve, being piloted, does not require the use of magnetic materials in contact with peroxide.

7.5.9 Reaction Motor Chambers

The shells of the reaction motor chambers have been fabricated from Types 304 and 316 stainless steel. These materials were selected because of their resistance to corrosive attack from the highly oxidized decomposition products and they exhibit relatively high strength properties at elevated temperatures. Compatibility with hydrogen peroxide was not a primary consideration for the motors. The materials used for the motors have good welding and brazing characteristics to permit easy fabrication. The 500 pound motor is an investment casting of 316 stainless steel.

7.5.10 Nitrogen Relief Valves

As in the case of the pressure reducers, the nitrogen relief valves are fabricated from aluminum alloy because of the comparative lightness and high strength. These valves are not peroxide compatible.

7.5.11 Seats and Seals

The components employed in the nitrogen systems make use of seals, "O"-rings and seats which are not hydrogen peroxide compatible, while the components in the hydrogen peroxide systems use either

KEL-F, Viton "A" or Teflon which are compatible with hydrogen peroxide. In general, KEL-F is used in the peroxide valving because of the possibility of cold flow problems with Teflon even though Teflon has better high temperature properties than KEL-F.

For the nitrogen system, the AN 6920 series "O"-rings are specified. In the peroxide system, several different "O"-ring materials have been used. The first materials used extensively were Dow Corning Compound LS53 and KEL-F. The LS53 seals are still used for "O"-rings in some of the valves. However, most of the static seals in the system have been converted from LS53 to Viton "A" which is a much more satisfactory static pressure seal.

There are several other instances where other seal arrangements have been used. The original seal design for the top of the peroxide tanks was a flat type seal made of Teflon. This material was found to be unsatisfactory because of its cold flow characteristics which resulted in leakage with time. This seal has been changed to a Viton "A" "O"-ring. The seal used in the 500 pound thrust motor between the catalyst bed and the nozzle is a flexitallic type which will endure the high temperatures experienced in the motor.

7.5.12 Latching Type Valve

The latching valve body is 2024-T4 aluminum alloy and the piston adjacent to the vent port is 303 stainless steel. The piston seat and stem are Teflon and 416 stainless steel, respectively. The vent portion of the valve has a 6061-T6 aluminum alloy body, Viton "A" seals, and the other parts are 302 stainless steel. The above parts as well as the 2024-T4 exit port of the latching valve must demonstrate little activity when in contact with 90 percent hydrogen peroxide.

7.5.13 Marotta MV 100T Thrust Reduction Valve

This valve used in the third stage thrust reduction system and in conjunction with the 14 pound motors is made from 6061 aluminum alloy. KEL-F and Viton "A" seals and seats are used where contact with hydrogen peroxide occurs.

7.5.14 Koehler (3-110634) Bleed Valve

The Koehler bleed valve is 304 stainless steel using Viton "A" seals.

7.5.15 Hoke Charging Valve

This needle valve has a metal to metal seat and the steam "O"-ring seal is Teflon. The valve body and stem are 316 stainless steel.

8.0 REFERENCES

8.1 L 1150 dated 21 October 1960, "Design, Fabrication, Ground Testing, Instrumentation, Assembly, Preparation for Launch of the Scout Research Vehicle", Vought Astronautics

8.2 304-3A dated 31 October 1960, "Procurement Specification for Scout Research Vehicle, "B" Section Reaction Thrust System, Hydrogen Peroxide", Vought Astronautics

8.3 304-4A dated 31 October 1960, "Procurement Specification for Scout Research Vehicle, "C" Section Reaction Thrust System, Hydrogen Peroxide", Vought Astronautics

8.4 N. S. Davis, Jr. and James C. McCormick, "Design of Catalyst Packs for the Decomposition of Hydrogen Peroxide", ARS Paper No. 1246-60, July 1960

8.5 Asher H. Shapiro, "The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol. I", The Ronald Press Company, New York, 1953

8.6 M. J. Zucrow, "Aircraft and Missile Propulsion", Vol. II, John Wiley & Sons, Inc., New York, 1958

8.7 Bulletin No. 46, "Concentrated Hydrogen Peroxide", Becco Chemical Division, Food Machinery & Chemical Co., November 1958

8.8 Bulletin No. 40, "Equipment for Use With High-Strength Hydrogen Peroxide", Becco Chemical Division, Food Machinery & Chemical Company, March-April 1952

8.9 Bulletin No. 3, "Highly Concentrated Hydrogen Peroxide", Becco Chemical Division, Food Machinery & Chemical Company, December 1947

8.10 Bulletin No. 104, "Materials of Construction for Equipment in Use With Hydrogen Peroxide", Becco Chemical Division, Food Machinery & Chemical Company, October 1959

8.11 Bulletin No. 77, "Concentrated Hydrogen Peroxide as a Propellant", Becco Chemical Division, Food Machinery & Chemical Company, April 1956

8.12 Bulletin No. 107, "High Strength Hydrogen Peroxide Monopropellant and Bi-propellant Performance Data", Becco Chemical Division, Food Machinery & Chemical Company

8.13 "Concentrated H_2O_2 Monopropellant and Bi-propellant Performance Data Plus Some Property Data for Liquid and Vapor", Becco Chemical Division, Food Machinery & Chemical Company, August 1958

8.14 Handbook, "Field Handling of Concentrated Hydrogen Peroxide", NAVAER 06-25-501, 15 October 1958

Rev. A

TABLE I

COMPONENT WEIGHTS
SECOND AND THIRD STAGES

SECOND STAGE

Component	Qty	Part No.	Assy. Wt. Lbs.	Total Wt. Lbs.
1. Fuel Storage Tank	10	3593L-0004	6.20	62.00
2. Nitrogen Storage Tank	2	3593A-0004	12.40	24.80
3. 500 Pound Chamber and Valve Assembly	4	3593R-0043	12.90	51.60
4. (2) 20 Pound Chamber and Valve Assemblies	2	3593M-0004	3.96	7.92
5. (2) 40 Pound Roll Chamber and Valve Assemblies	2	NASA 804731 or WK 3593-099	4.46	8.92
6. Fuel Charging Valve	1	2169B-0023	1.06	1.06
7. Valve Assembly, Pneumatic (3 Way)	1	3593H-0014	2.10	2.10
8. Overboard Chamber Assembly	1	2169S-0004	0.25	0.25
9. Pressure Reducer and Filter	1	3593-C-0002	2.09	2.09
10. Relief Valve and Drain Assy.	1	3593B-0022	0.66	0.66
11. Nitrogen Relief Valve	1	872798-0525	0.25	0.25
12. Nitrogen Charging Valve and Fitting	1	2169K-1762	0.75	0.75
13. 1/2 Inch Check Valve (Pneumatic System)	1	2169F-0003	0.47	0.47
14. Koehler Hydrogen Peroxide Bleed Valve	1	3-110634	0.15	0.15

- continued -

TABLE I
(Continued)

THIRD STAGE

Component	Qty	Part No.	Assy. Wt. lbs.	Total Wt. lbs.
1. Fuel Tank Assembly	2	3593N-0004	3.60	7.20
2. Nitrogen Tank Assembly	2	2172M-0014	4.40	8.80
3. 2.2 Pound Chamber and Valve Assembly	2	3593R-0054	0.90	1.80
4. 14 Pound Chamber and Valve Assembly (L. H.)	2	3593X-0004	1.92	3.84
5. 14 Pound Chamber and Valve Assembly (R.H.)	2	3593X-0014	1.92	3.84
6. 40 Pound Chamber and Valve Assembly	4	3593L-0074	2.23	4.46
7. Fuel Charging Valve	1	3593B-0002	0.88	0.88
8. Pneumatic (3 Way) Valve Assy.	1	3593H-0004	2.10	2.10
9. Overboard Chamber Assembly	1	2169S-0004	0.25	0.25
10. Pressure Reducer and Filter Assembly	1	2172E-0212	0.85	0.85
11. Relief Valve and Drain Assy.	1	3593B-0012	0.66	0.66
12. Nitrogen Relief Valve	1	872798-0525	0.25	0.25
13. 1/4 Inch Check Valve (Pneumatic System)	1	2172F-0002	0.16	0.16
14. 2 Pound Reducer and Filter Assembly	1	2172R-0512	0.10	0.10
15. Koehler Hydrogen Peroxide Bleed Valve	1	3-110634	0.25	0.25
16. Marotta Thrust Control Valve	2	210753	0.80	1.60

TABLE II

MAJOR DESIGN REQUIREMENTS

Requirement		Second Stage	Third Stage
Rocket Motor		500 Lb. Motor	40 Lb. Motor
	**Condition 1	627 ± 57 lbs.	44 ± 4.4 lbs.
	**Condition 2	596.7 ± 87.7 lbs.	
Design Thrust Levels		20 Lb. Motor	14 Lb. Motor
	**Condition 1	22.8 ± 4.6 lbs.	14 ± 1.4 lbs. 3 ± 1.0 lbs. 2 Lb. Motor
	**Condition 2	21.8 ± 5.5 lbs.	2.2 ± 0.44 lbs.
	Established based on tolerance percent of 20# motors	40 Lb. Motor Retrofit	
	Condition 1	44 ± 8.8 lbs.	- - - - - - - - -
	Condition 2	42 ± 11.0 lbs.	- - - - - - - - -
Minimum Total Impulse	100% duty cycle	25,560 lb-sec.	2,560 lb-sec.
	Intermittent operation[1]	21,300 lb-sec.	2,240 lb-sec.
Hydrogen Peroxide Temperature at Inlet to Reaction Motor		40 to 160°F	40 to 160°F
Nitrogen Pressurizing Gas Temperature		40 to 160°F	40 to 160°F
Nominal Nitrogen Storage Pressure		3000 psig	1000 psig
Power Requirements for Thrust Control Valves		Coil Resistance - 28 ± 2 at 80°F; Actuation Signal - 26 volts min.; Drop-out Current - 50 ma min.	(Same as for second stage)
Ambient Pressure for Rocket Motor Design		Pressure at 100,000 ft. altitude	7 x 10-3 in. Hg. Abs.
Regulated Nitrogen Pressure		* 525 ± 10 psig (no flow)	* 455 ± 10 psig (no flow)

1 1 cps and 0.150 second signal duration

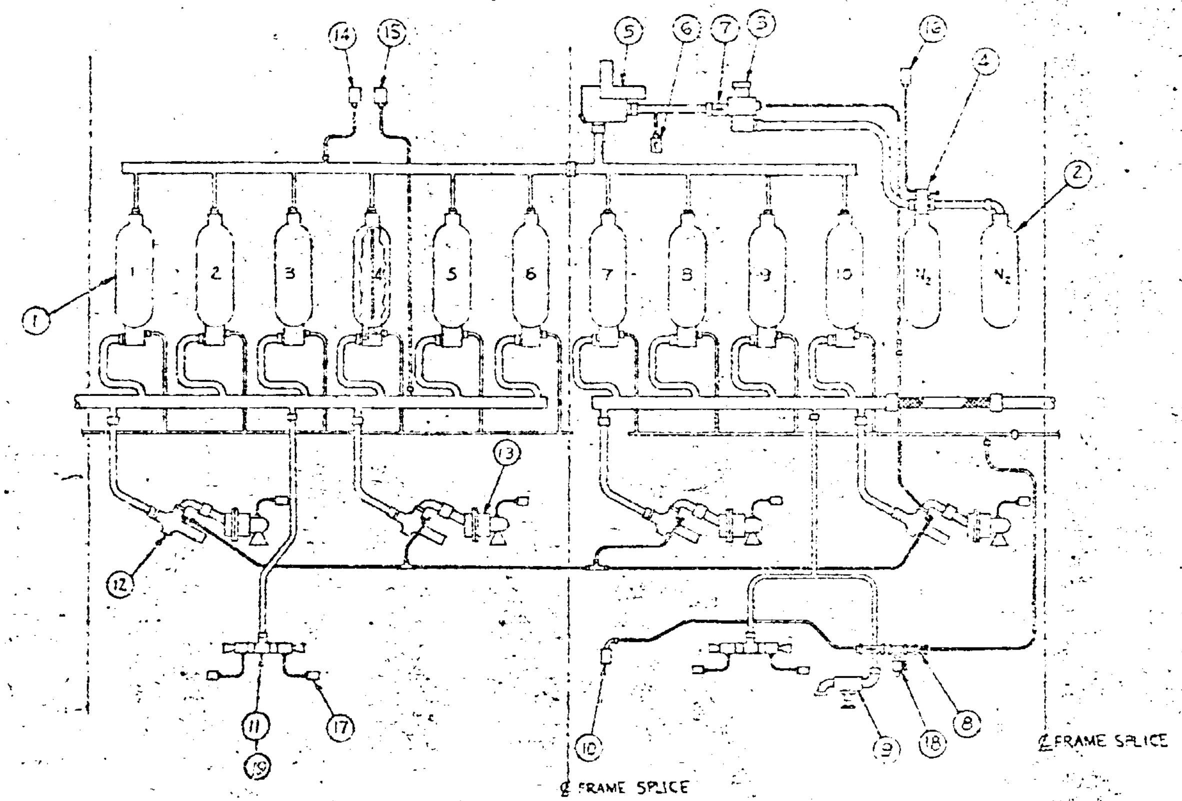
* Not originally specified - established through system development

** Reference: Vought Astronautics Specification 304-3A

TABLE III

HYDROGEN PEROXIDE TANKAGE CAPACITY

	Second Stage	Third Stage
Total Impulse - Lb-Sec. (100% Duty Cycle)	25,560	2,560
Average Specific Impulse $\left(\frac{\text{Lb-Sec}}{\text{Lb}}\right)$	144	144
Required Weight of Hydrogen Peroxide - Lbs.	178	17.8
Actual On-Board Weight of Hydrogen Peroxide - Lbs. (Includes Tanks, Lines, etc.)	185	19.2
Actual Usable Weight of Hydrogen Peroxide - Lbs.	182.0	18.2
Total Impulse - Lb-Sec. (Intermittent Operation)	21,300	2,240
Required Specific Impulse to Obtain Total Impulse for Intermittent Operation - Sec.	117	123
Required Hydrogen Peroxide Storage Volume - Cu. In. (Density of 86.9 lb/ft^3)	3,640	364
Nominal Volume of Hydrogen Peroxide Tankage - Cu. In.	4,000	400



ITEM	REQ'D	NOMENCLATURE	PART NO.
1	10	H_2O_2 TANK ASSY	WK35931-[illegible]
2	2	N_2 TANK ASSY	WK3593A-0004
3	1	N_2 PRESS REDUCER	WK3592[illegible]
4	1	N_2 CHARGING VALVE	[illegible]
5	1	N_2 SOLENOID VALVE	WK[illegible]-0014
6	1	N_2 RELIEF VALVE	[illegible]
7	1	N_2 CHECK VALVE	WK[illegible]-0003
8	1	H_2O_2 DRAIN & RELIEF ASSY	WK[illegible]
9	1	H_2O_2 CHARGING VALVE	WK21698-0023
10	1	H_2O_2 OVERBOARD DUMP	WK21695-0002
11	2	2013 MOTOR & VALVE ASSY	[illegible] 304781
12	4	500 LB MOTOR VALVE ASSY	[illegible]
13	4	500 LB MOTOR ASSY	WK2162[illegible]
14	1	REG N_2 PRESS SWITCH	[illegible]
15	1	H_2O_2 PRESS TRANSDUCER	[illegible]
16	1	UNREG N_2 PRESS TRANS.	[illegible] 7251-7
17	3	MOTOR PRESS SWITCH	[illegible]
18	1	H_2O_2 BLEED VALVE	[illegible]
19	2	2013 MOTOR & VALVE ASSY	[illegible]

→ WK 2593-049

FIGURE 1

REV. A

11027-1A2

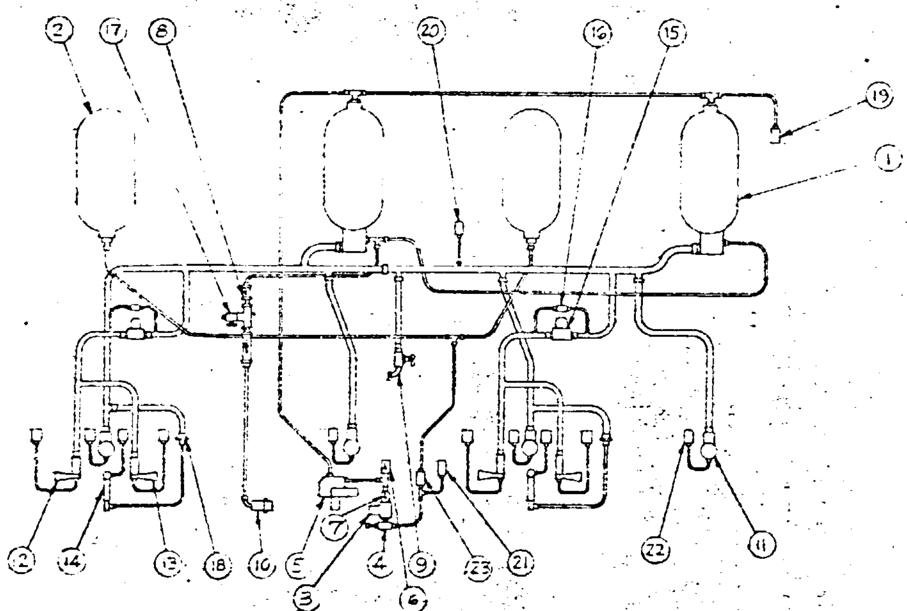
NONE

SCHEMATIC

2ND STG REACTION CONTROL [illegible]

TRANS "B" UPR

23-000319



ITEM	REQD	NOMENCLATURE	PART NO.
1	2	H_2O_2 TANK ASSY	WK3593N-0004
2	2	N_2 TANK ASSY	WK3593M-0014
3	1	N_2 PRESS REDUCER	WK2172E-0223
4	1	N_2 CHARGING VALVE	MS 28889-1
5	1	N_2 SOLENOID VALVE	WK3593H-0004
6	1	N_2 RELIEF VALVE	872798-0525
7	1	N_2 CHECK VALVE	WK2172F-0002
8	1	H_2O_2 DRAIN & RELIEF ASSY	WK3593B-0012
9	1	H_2O_2 CHARGING VALVE	WK3593P-0002
10	1	H_2O_2 OVERBOARD DECOMP	AK2169S-0004
11	4	40LB MOTOR & VALVE ASSY	WK3593L-0074
12	2	14-3LB MOTOR & VALVE ASSY-LH	WK3593K-0004
13	2	14-3LB MOTOR & VALVE ASSY-RH	WK3593K-0014
14	2	2.2 LB MOTOR & VALVE ASSY	WK3593R-0054
15	2	THRUST REDUCTION VALVE	MAROTTA 210753
16	2	BY-PASS RESTRICTOR	23-000445-1
17	1	H_2O_2 BLEED VALVE	ROBINSON [illegible]
18	2	2.2 LB MOTOR VALVE FILTER	WK3593A-0222
19	1	REG N_2 PRESS SWITCH	[illegible]
20	1	H_2O_2 PRESS TRANSDUCER	[illegible]
21	1	UNREG N_2 PRESS TRANS	[illegible]
22	10	MOTOR PRESS SWITCH	[illegible]
23	1	N_2 THERMISTOR HOUSING	23-000466-1

REPORT AST/EIR 12434
FIGURE 2
PAGE

SCHEMATIC
3RD STG REACTION CONTROL SYS
TRANSITION C UPPER

NONE

11C27-182

23-000320

FIGURE 3

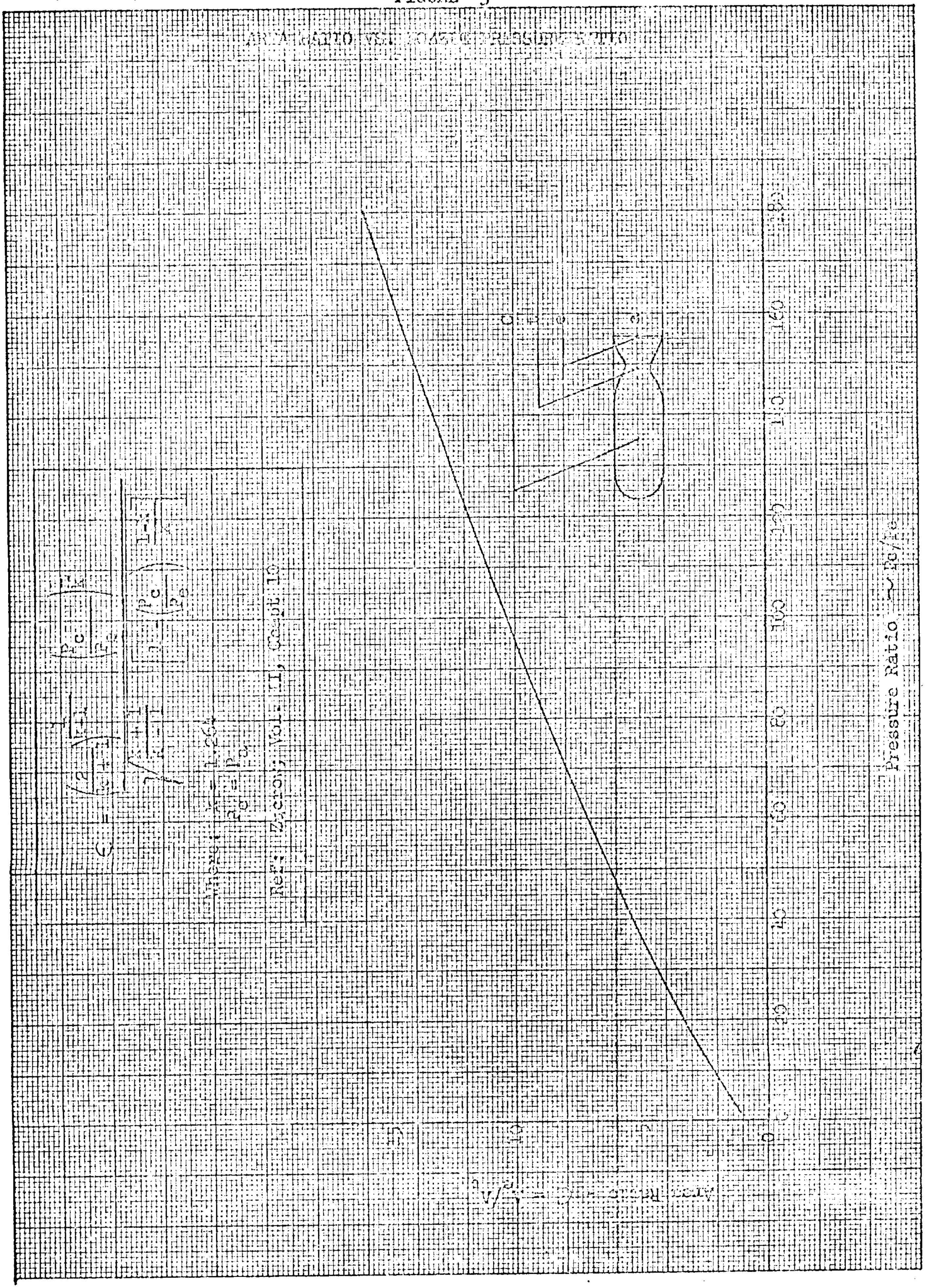

Where: k = 1.264
Pe = Pa
Ref: Zucrow, Vol. II, Chapt 10
C
e
0
20
40
60
80
100
120
140
160
180
0
5
10
15
Pressure Ratio ~ Pc/Pe

FIGURE 4

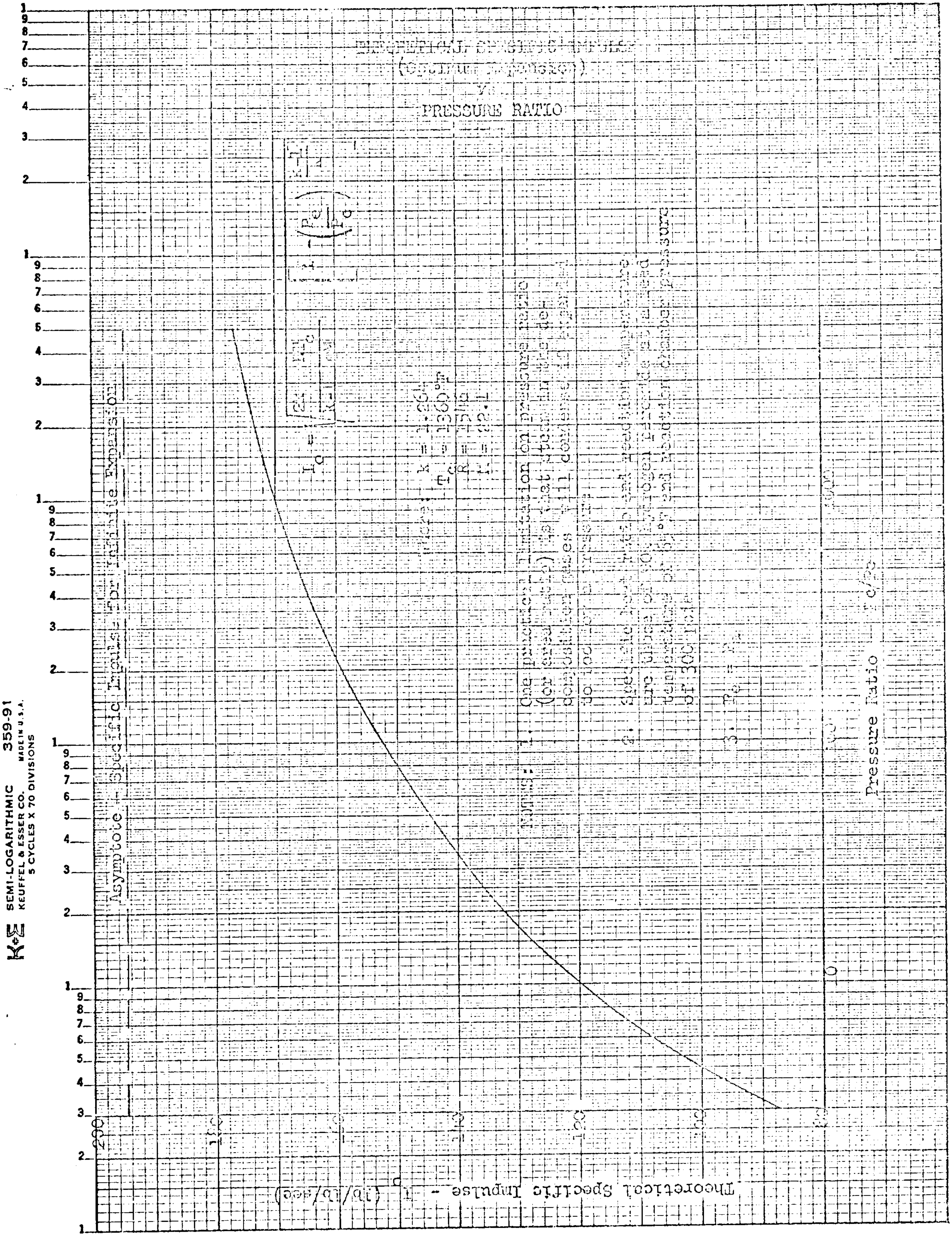

THEORETICAL SPECIFIC IMPULSE
(Optimum Expansion)
VS
PRESSURE RATIO
Asymptote - Specific Impulse for Infinite Expansion
where: k = 1.264
T_c = 1360°F
NOTES: 1. One practical limitation on pressure ratio (or area ratio) is that steam in the decomposition gases will condense if expanded to too low a pressure
2. Specific heat ratio and reaction temperature are those of 90% hydrogen peroxide at a feed temperature of 65°F and reaction chamber pressure of 300 psia
3. $P_e = P_a$
Theoretical Specific Impulse - I_p (lb/lb/sec)
Pressure Ratio - P_c/P_e
200
120
10
100
1000
SEMI-LOGARITHMIC 359-91
KEUFFEL & ESSER CO. MADE IN U.S.A.
5 CYCLES X 70 DIVISIONS

FIGURE 5

RATIO OF THEORETICAL SPECIFIC IMPULSES

Vs.

NOZZLE PRESSURE RATIO

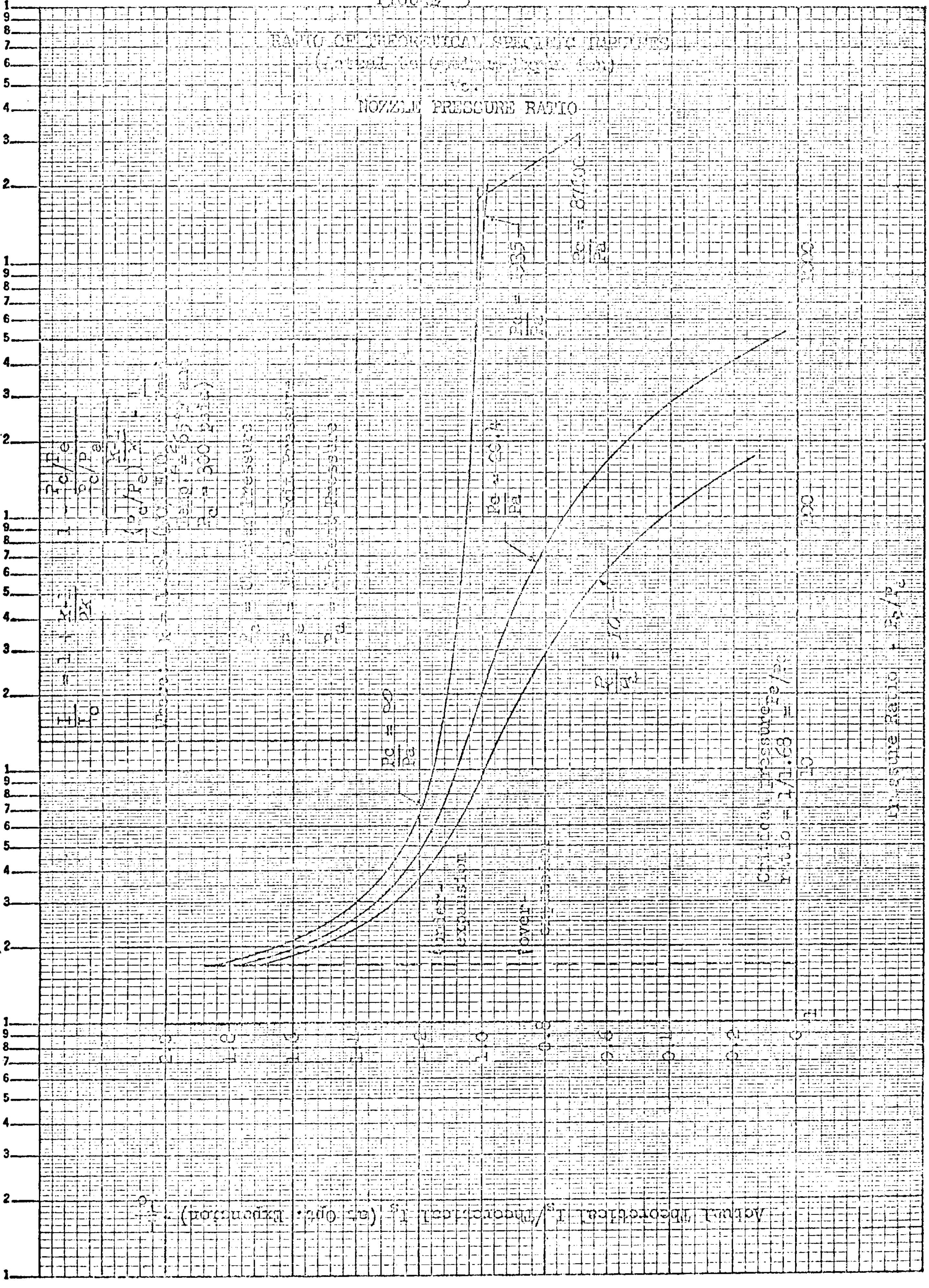


FIGURE 6

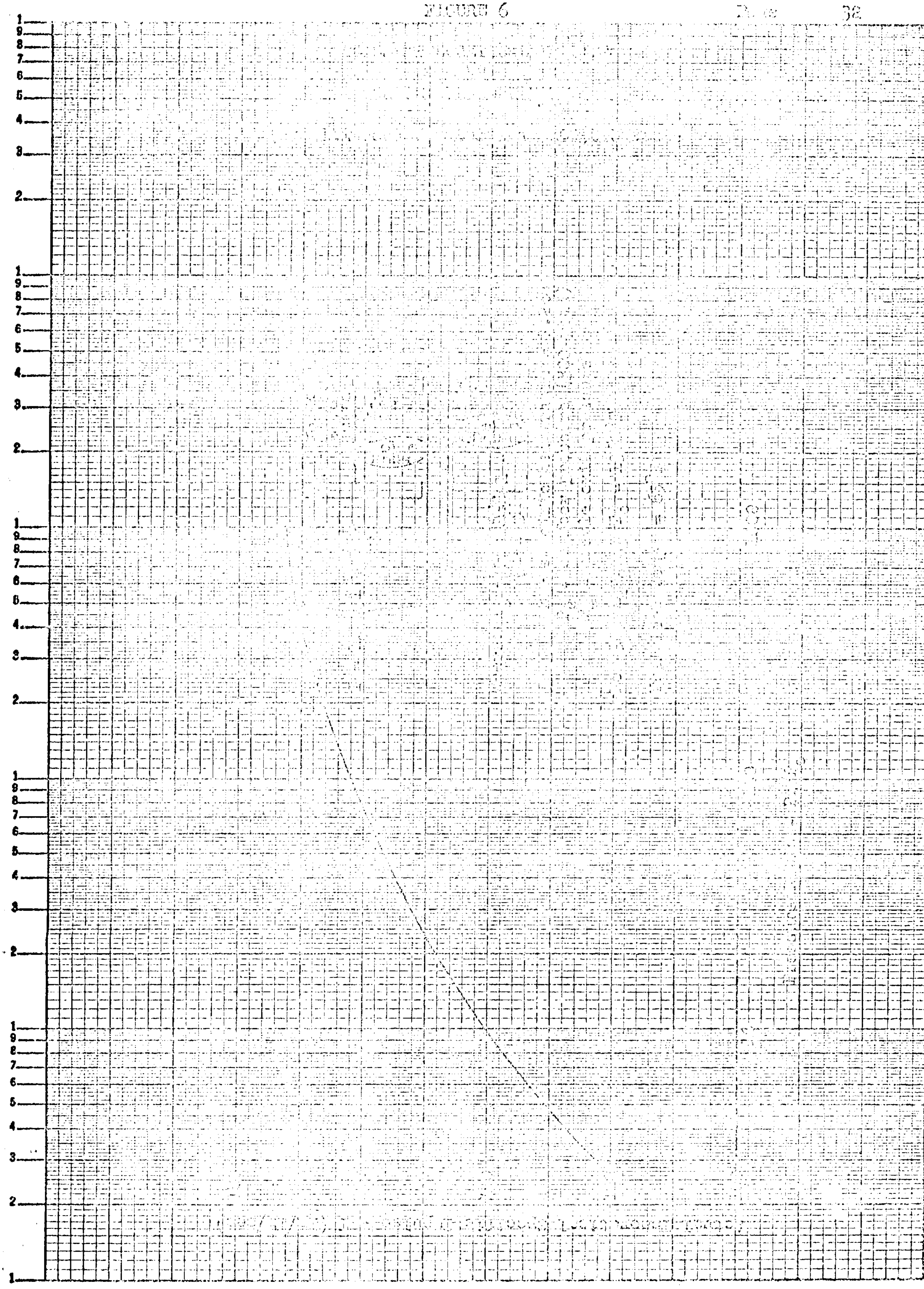


FIGURE 7

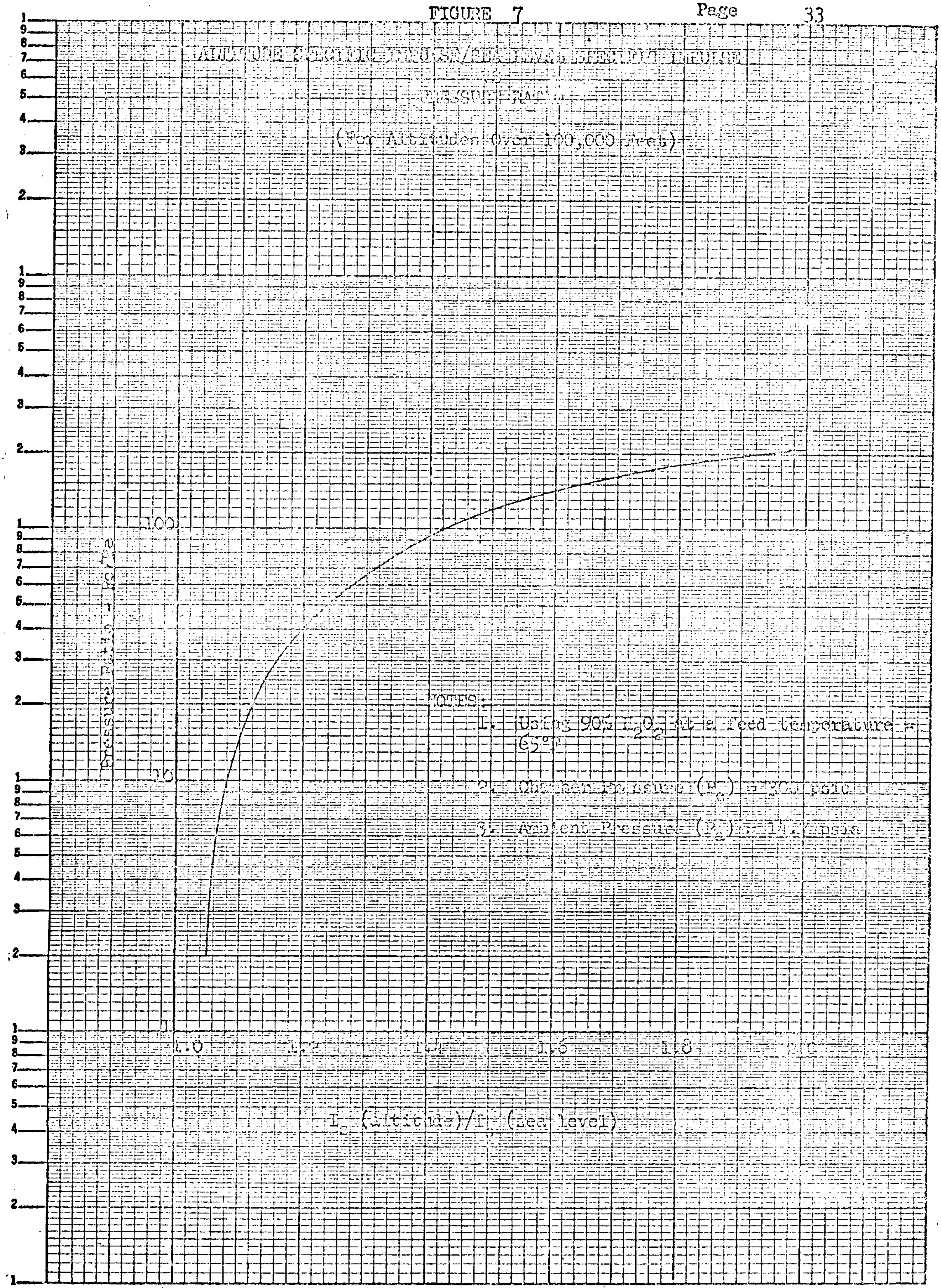
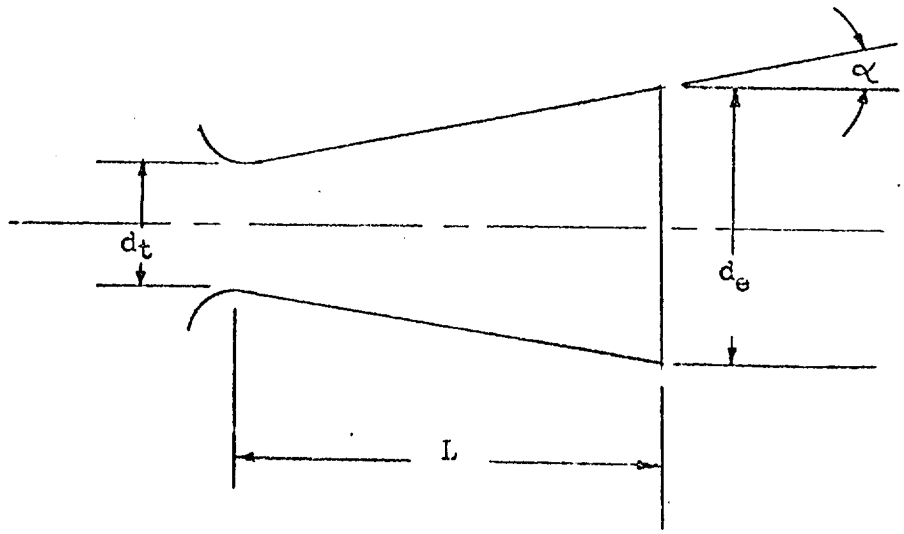

(For Altitudes Over 100,000 Feet)
Pressure Ratio
100
10
1
1.0
1.2
1.4
1.6
1.8
2.0
I_s (altitude)/I_s (sea level)
NOTES:
1. Using 90% H_2O_2 at a Feed Temperature = 65°F
2. Chamber Pressure (P_c)
3. Ambient Pressure (P_a)

FIGURE 8

ACTUAL THRUST NOZZLE DIMENSIONS



d_t = Throat Diameter
A_t = Throat Area
d_e = Exit Diameter
α = Half Angle
L = Nozzle Length = $\frac{(d_e - d_t)}{2 \tan \alpha}$

Stage	Nominal Motor Size	d_t (in)	A_t (in^2)	d_e (in)	(deg)	L (in)
2nd	500#	1.437	1.622	3.56	25°	2.276
2nd	Retrofit 40# Roll	0.373	0.1093	1.175	20°	1.10
2nd	20# Roll	0.290	0.0661	0.825	20°	0.735
3rd	40# Pitch and Yaw	0.373	0.1093	1.183	20°	1.113
3rd	14-3#	0.200	0.0314	0.775	7° 47'	2.103
3rd	2#	0.076	0.00454	0.265	20°	0.273

FIGURE 9

THEORETICAL REACTION MOTOR PERFORMANCE

	NOMINAL MOTOR SIZE	ALTITUDE THRUST F - #	CHAMBER PRESS. P_c - psia	NOZZLE THROAT AREA A_t-in^2	NOZZLE AREA RATIO	NOZZLE PRESS. RATIO P_c/P_e	NOZZLE EXIT RATIO P_e-psia	DESIGN AMB. PRESS. P_a-psia		ALT. THRUST COEF. $C_{f_{alt}}$	ACTUAL THRUST COEF. $C_{f_{act}}$	NOZZLE EFFICIENCY η_n	SPECIFIC IMPULSE I_s - sec	FLOW RATE $\dot{w}$-#/sec.	CATALYST X-SECT. AREA in^2	CATALYST LOAD FACTOR #/min/in^2	PEROXIDE TEMP. °F
Second Stage	500	570	214	1.622	6.14	47.6	4.49	0.155	1.264	1.647	1.647	1.00	157	3.58	10.13	21.2	65
	40 Roll Retrofit	44.0	236	0.1093	9.92	94.0	2.51	0.155		1.706	1.706		161	0.274	0.85	19.4	
	20 Roll	22.8	205	0.0661	8.09	70.0	2.93	0.155		1.680	1.680		159	0.144	0.421	20.5	
Third Stage	40 Pitch & Yaw	44.0	236	0.1093	10.06	97.0	2.44	0.00344		1.708	1.708		161	0.274	0.850	19.4	
	14	14.0	252	0.0314	15.02	164.0	1.54	0.00344		1.767	1.767		164	0.085	0.418	12.2	
	2	2.2	284	0.0045	12.16	122.0	2.33	0.00344		1.727	1.727		163	0.013	0.1625	4.8	

FIGURE 10

ACTUAL REACTION MOTOR PERFORMANCE

	NOMINAL MOTOR SIZE	ALTITUDE THRUST F - #	CHAMBER PRESS. P_c-psia	NOZZLE THROAT AREA A_t-in^2	NOZZLE AREA RATIO	NOZZLE PRESS. RATIO P_c/P_e	NOZZLE EXIT RATIO P_e-psia	DESIGN AMB. PRESS. P_a - psia		ALT. THRUST COEF. $C_{f_{alt}}$	ACTUAL THRUST COEF. $C_{f_{act}}$	NOZZLE EFFICIENCY η_n	SPECIFIC IMPULSE I_s - sec	FLOW RATE $\dot{w}$-#/sec.	CATALYST X-SECT. AREA in^2	CATALYST LOAD FACTOR #/min/in^2	PEROXIDE TEMP. °F
Second Stage	500	625	306	1.622	6.14	47.6	6.42	0.155	1.264	1.647	1.258	0.765	146	4.28	10.13	25.34	65
		597	293	1.622	6.14	47.6	6.15	0.155		1.647	1.258	0.764	146	4.09	10.13	24.20	
	40 Roll	44	259	0.1093	9.92	94.0	2.76	0.155		1.706	1.554	0.907	142	0.310	0.850	21.90	
		42	242	0.1093	9.92	94.0	2.58	0.155		1.706	1.583	0.931	142	0.296	0.850	20.90	
	20	22.8	213	0.0661	8.09	70.0	3.05	0.155		1.680	1.619	0.963	140	0.163	0.421	23.20	
		21.8	205	0.0661	8.09	70.0	2.93	0.155		1.680	1.609	0.957	140	0.156	0.421	22.20	
Third Stage	40	44.0	264	0.1093	10.06	97.0	2.72	0.00344		1.708	1.522	0.893	142	0.310	0.850	21.90	
	14	14.0	283	0.0314	15.02	164.0	1.73	0.00344		1.767	1.575	0.892	158	0.0886	0.418	12.71	
		3.0	71	0.0314	15.02	164.0	0.43	0.00344		1.767	1.348	0.762	152	0.0197	0.418	2.83	
	2	2.2	310	0.0045	12.16	122.0	2.54	0.00344		1.727	1.578	0.914	144	0.0153	0.1625	5.75	

FIGURE 11

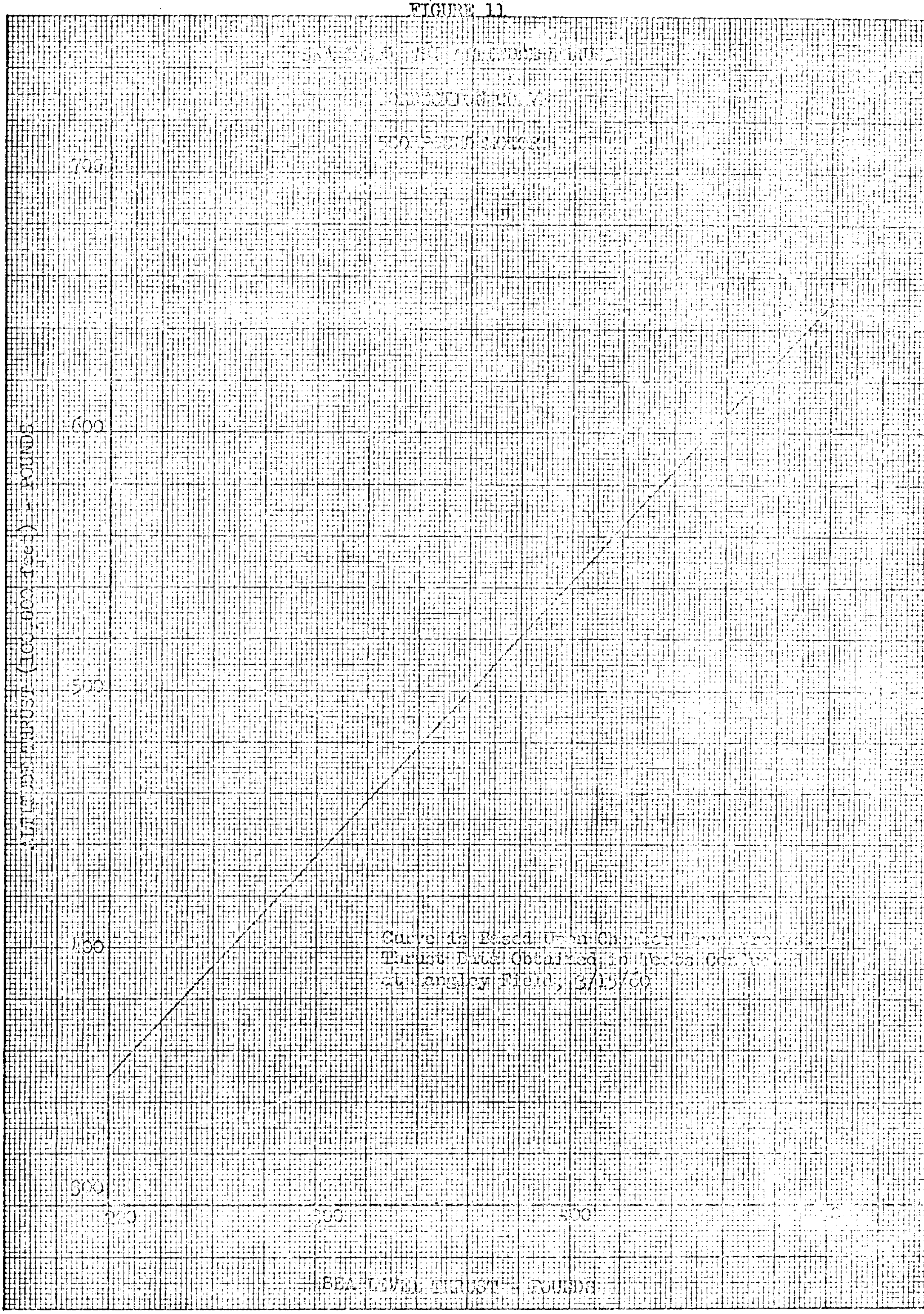

500
700
600
500
400
300
400
POUNDS
Curve is Based
at Langley Field, 3/15/60
SEA LEVEL THRUST - POUNDS

FIGURE 12

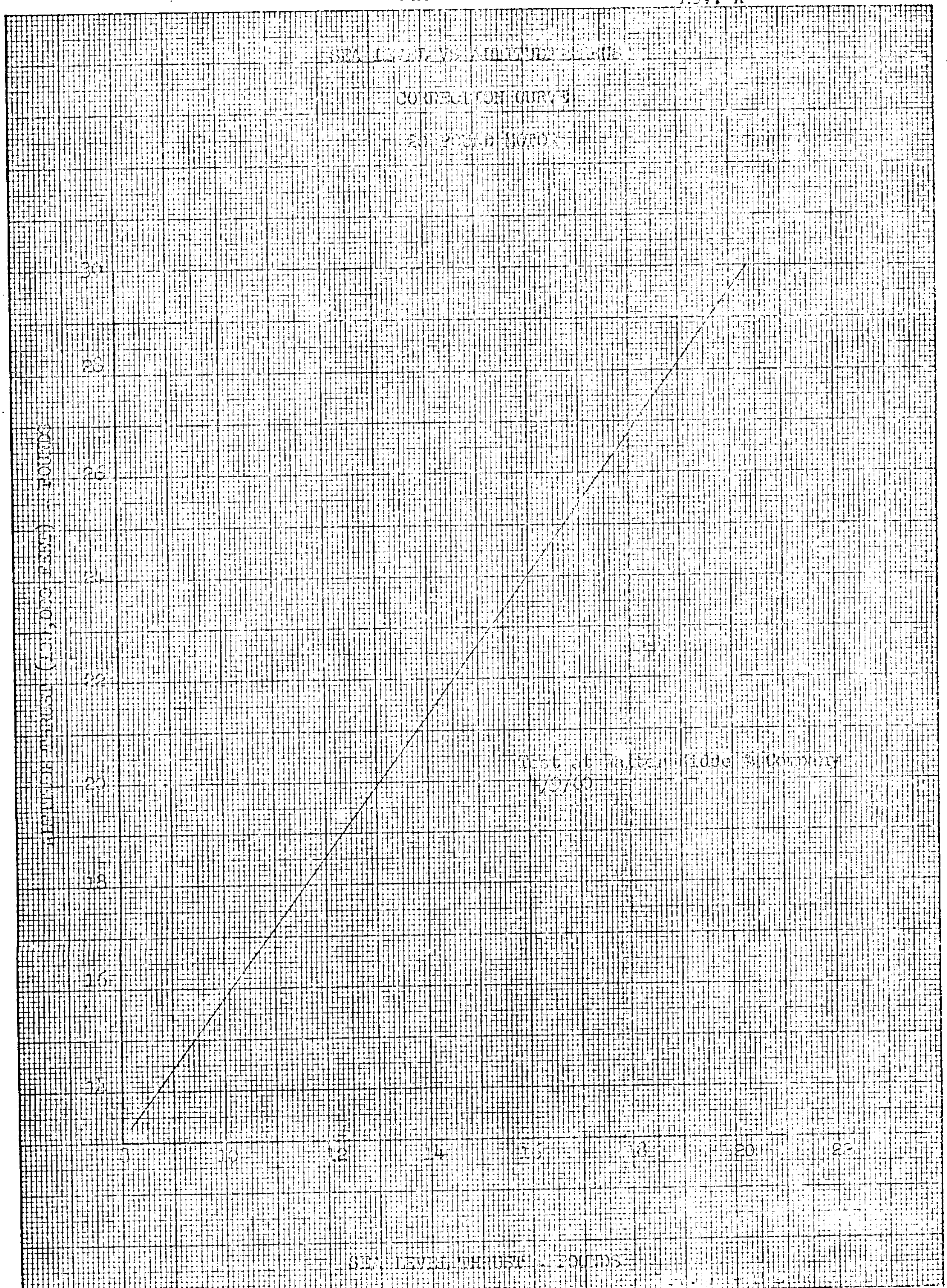

CORRECTION CURVE
30
28
26
24
22
20
18
16
14
10
12
14
18
20
SEA LEVEL THRUST - POUNDS

FIGURE 13

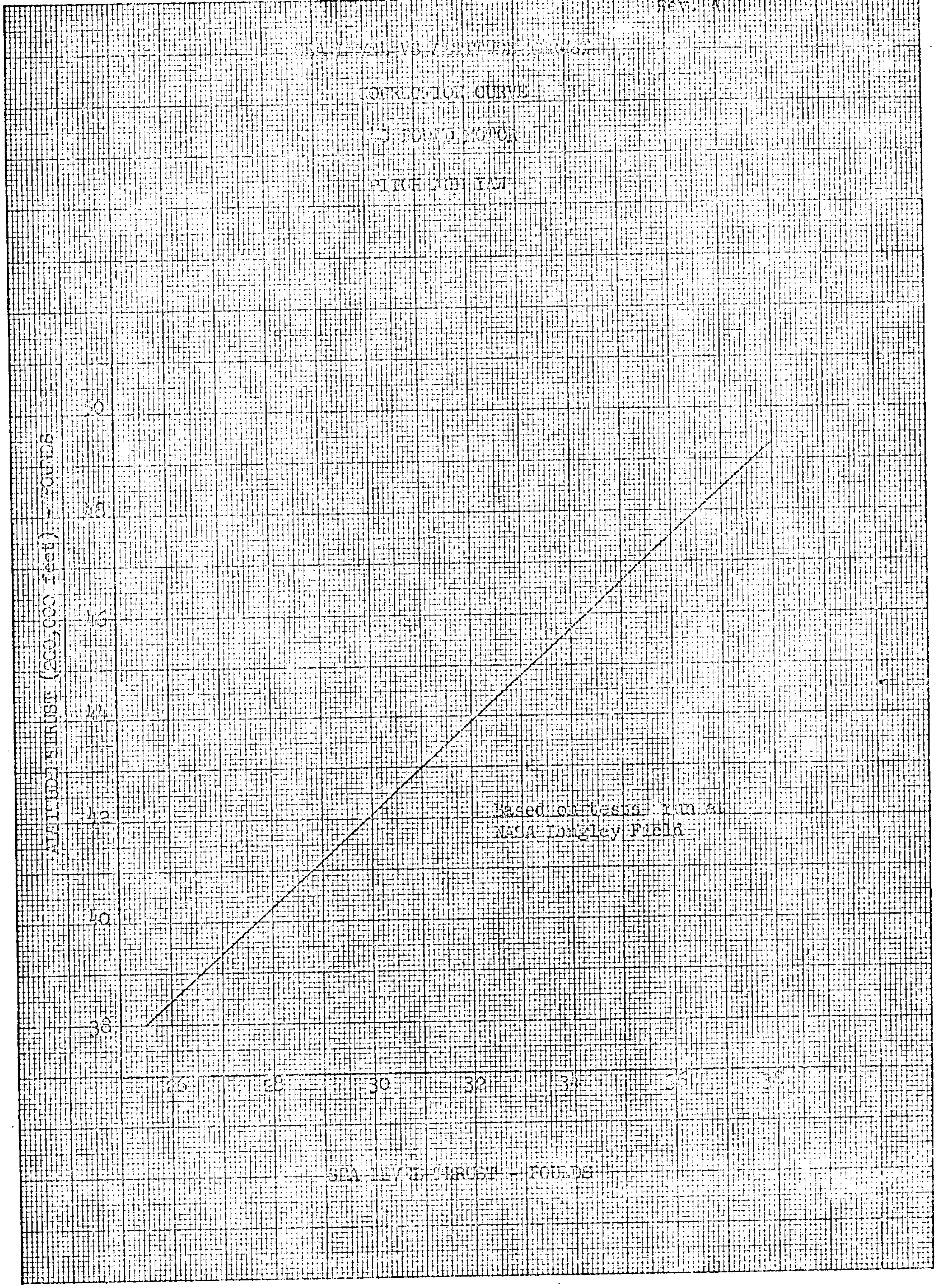


FIGURE 14

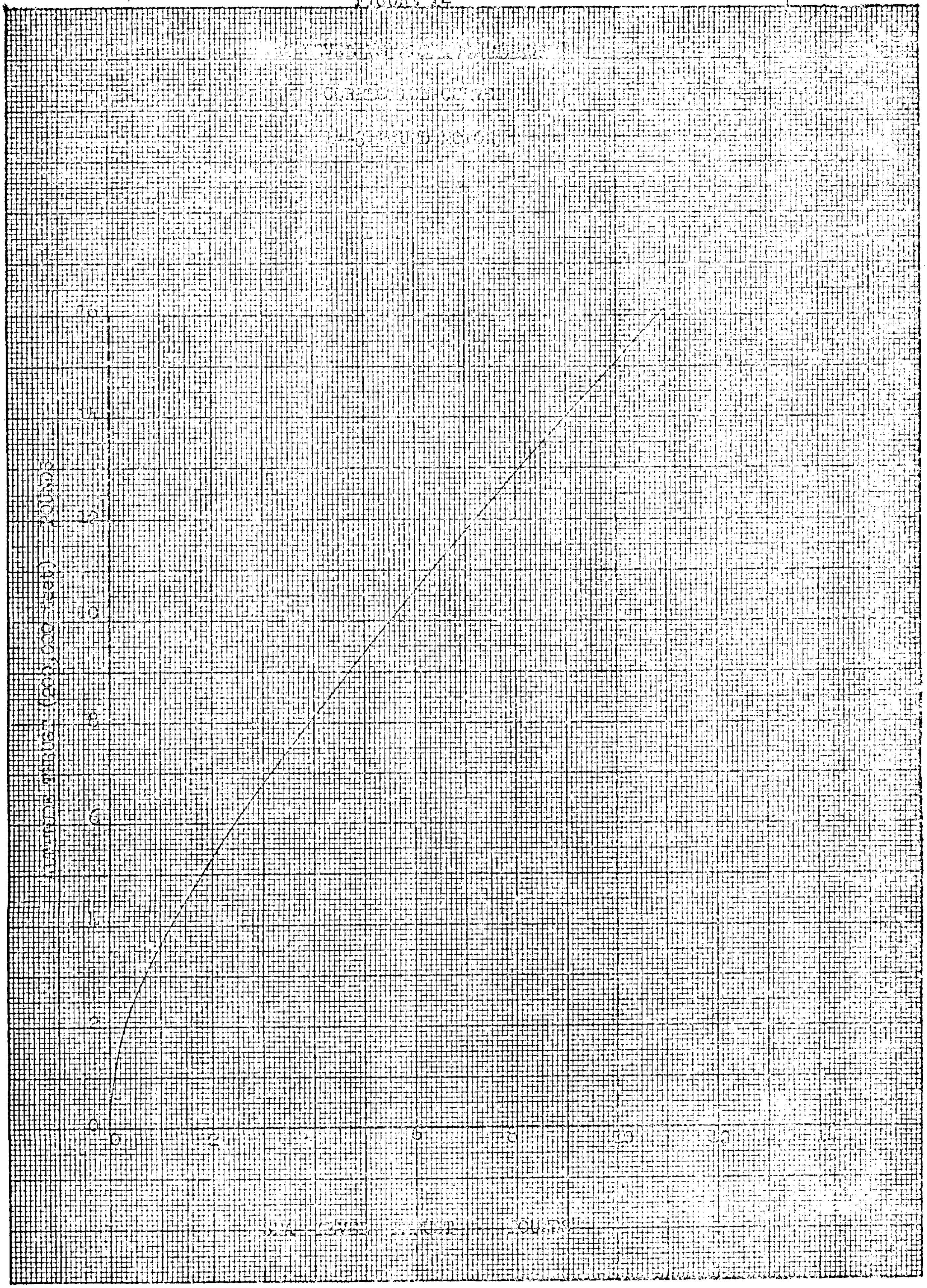


FIGURE 15

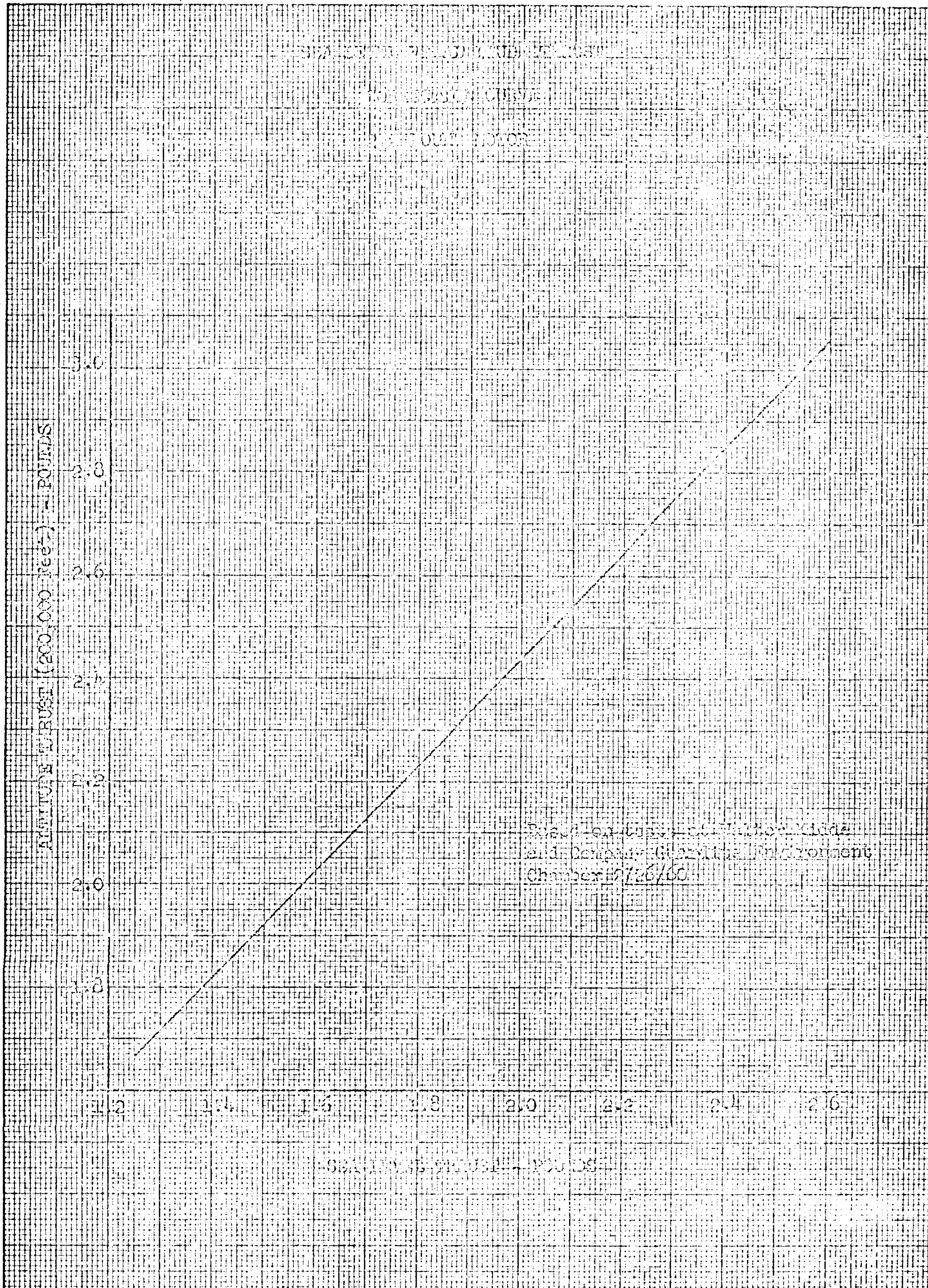


FIGURE 16

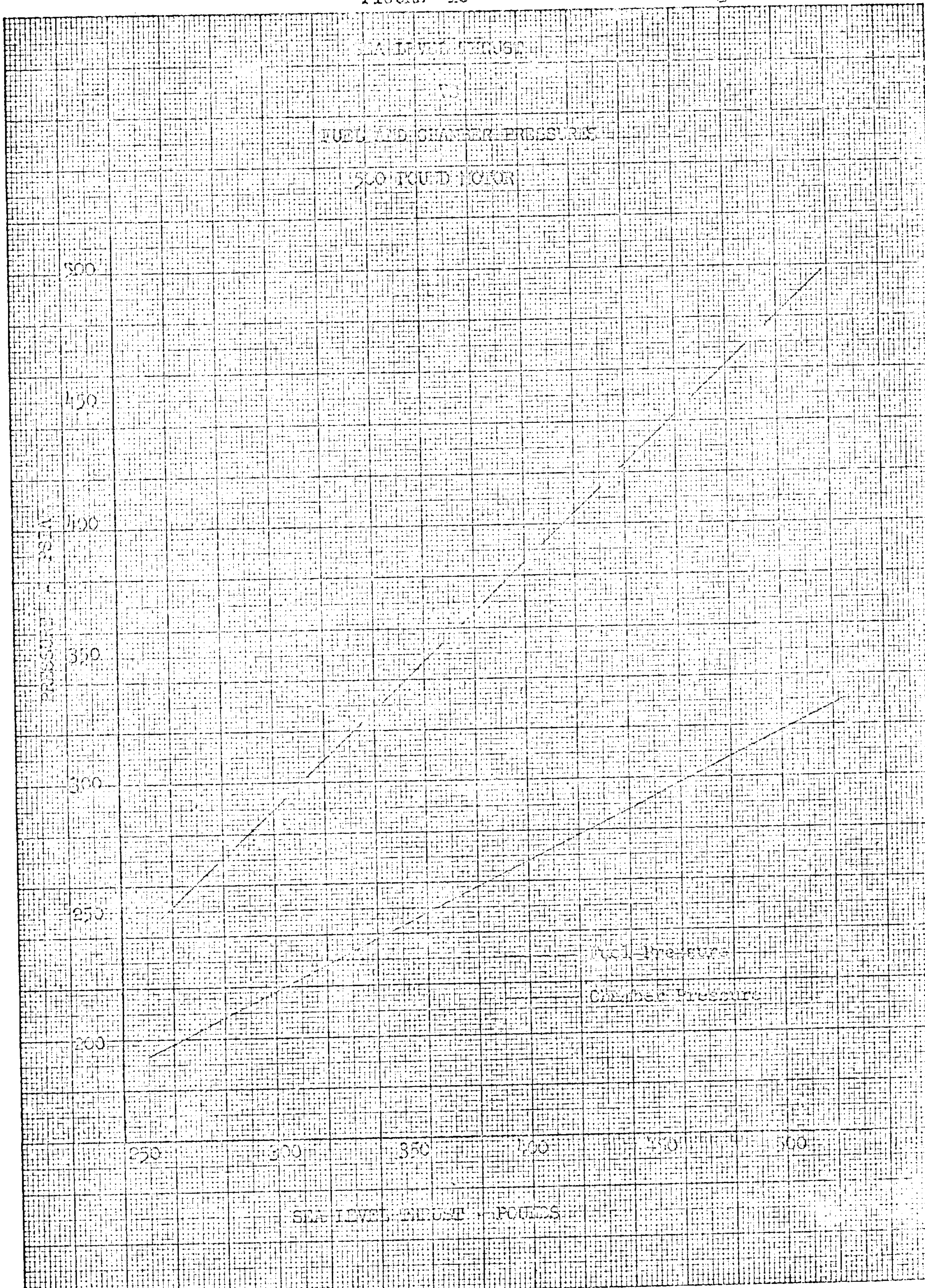

SEA LEVEL THRUST
VS
FUEL AND CHAMBER PRESSURES
500 POUND MOTOR
PRESSURE - PSIA
500
450
400
350
300
250
200
Fuel Pressure
Chamber Pressure
250
300
350
400
450
500
SEA LEVEL THRUST - POUNDS

FIGURE 17

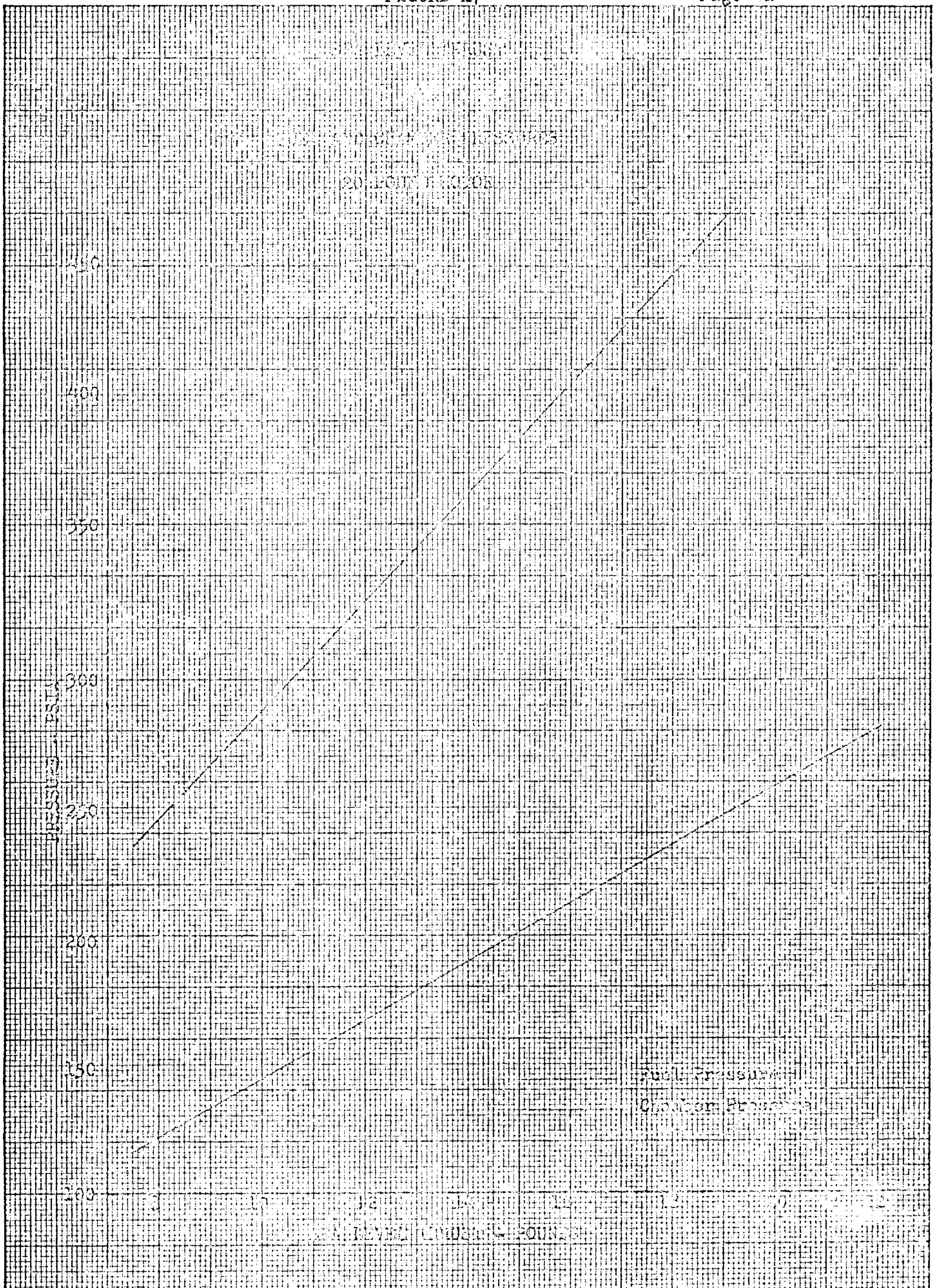


FIGURE 18

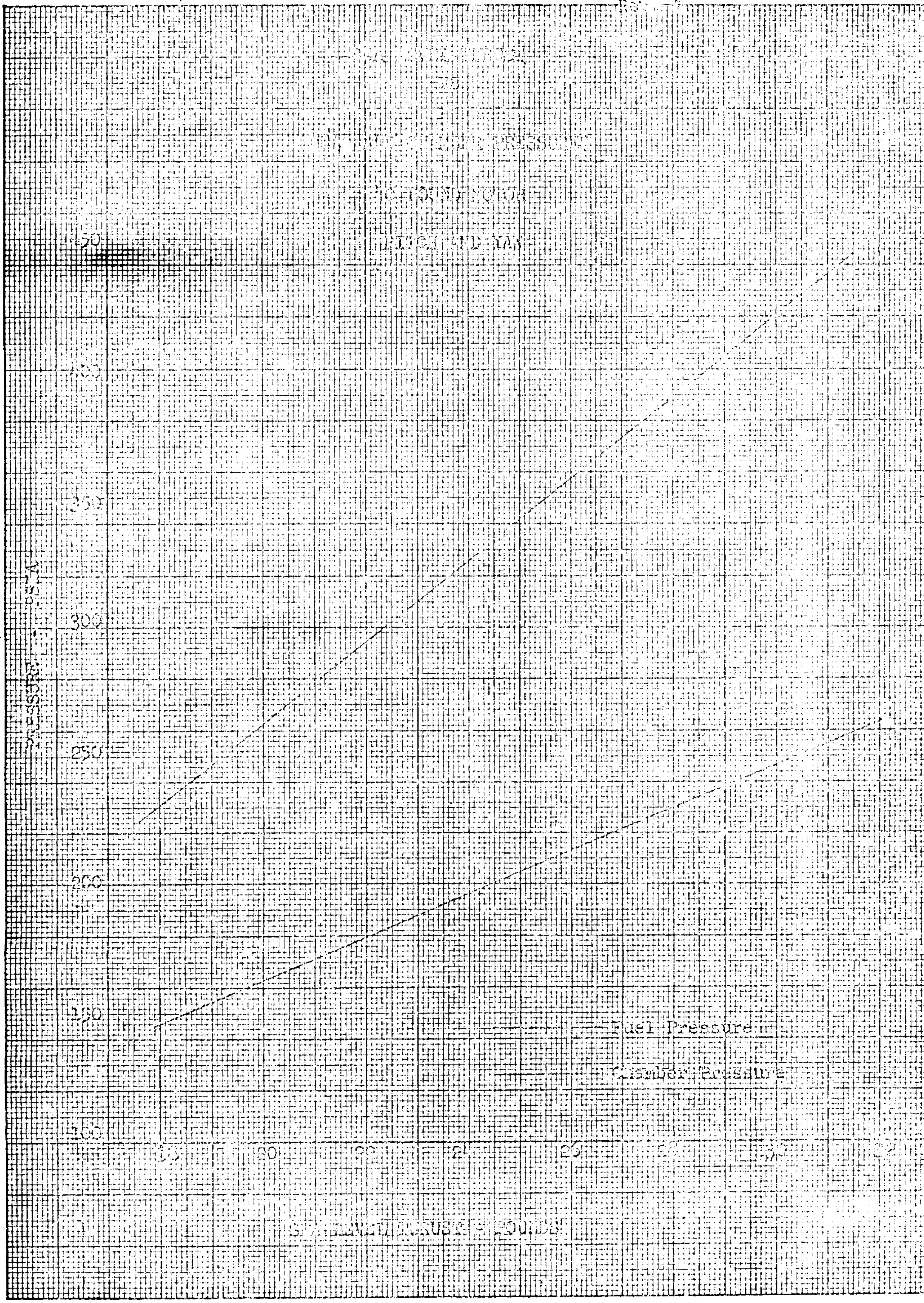

450
400
350
300
250
200
150
100
Fuel Pressure
Chamber Pressure

FIGURE 19

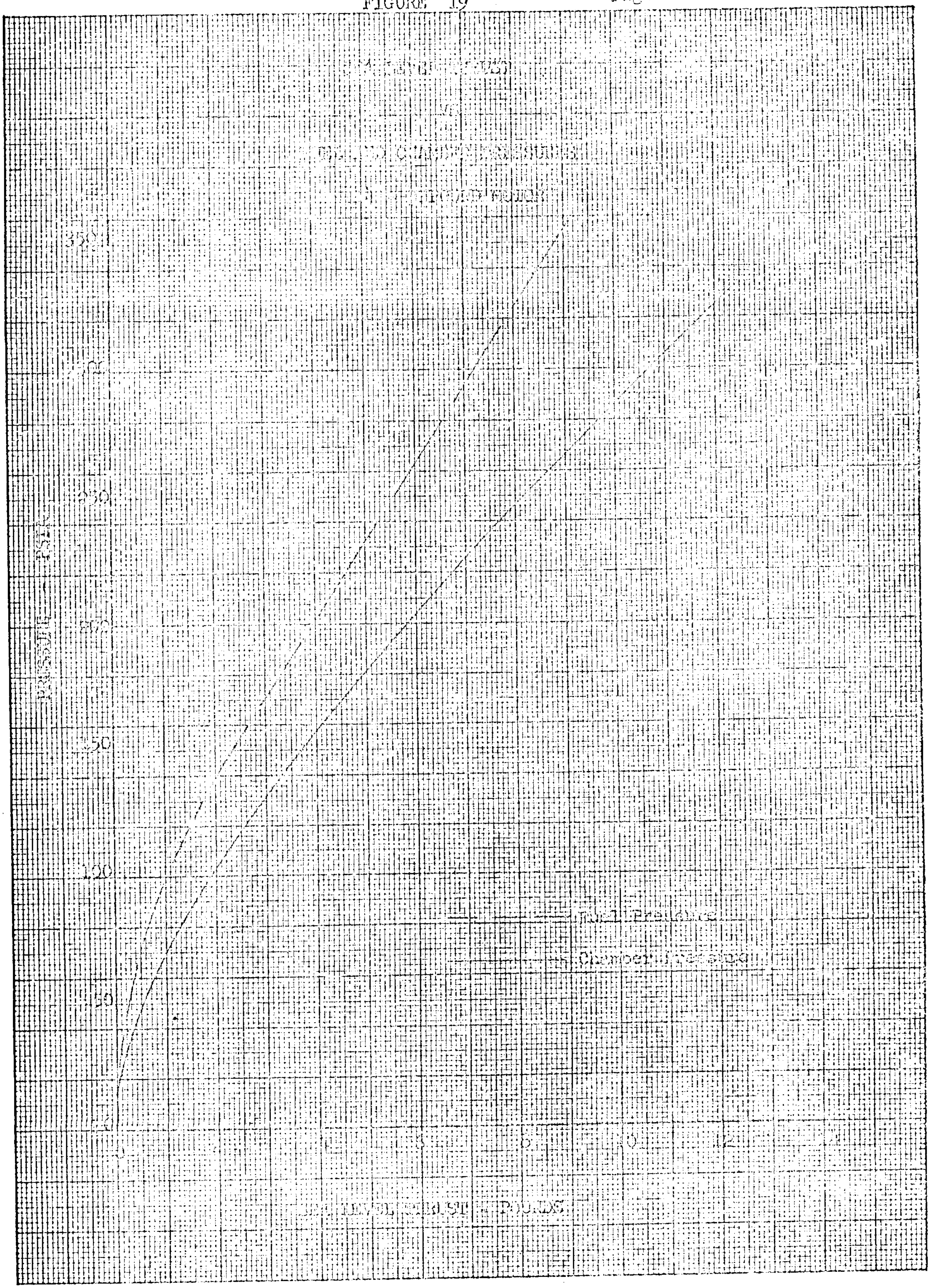


FIGURE 20

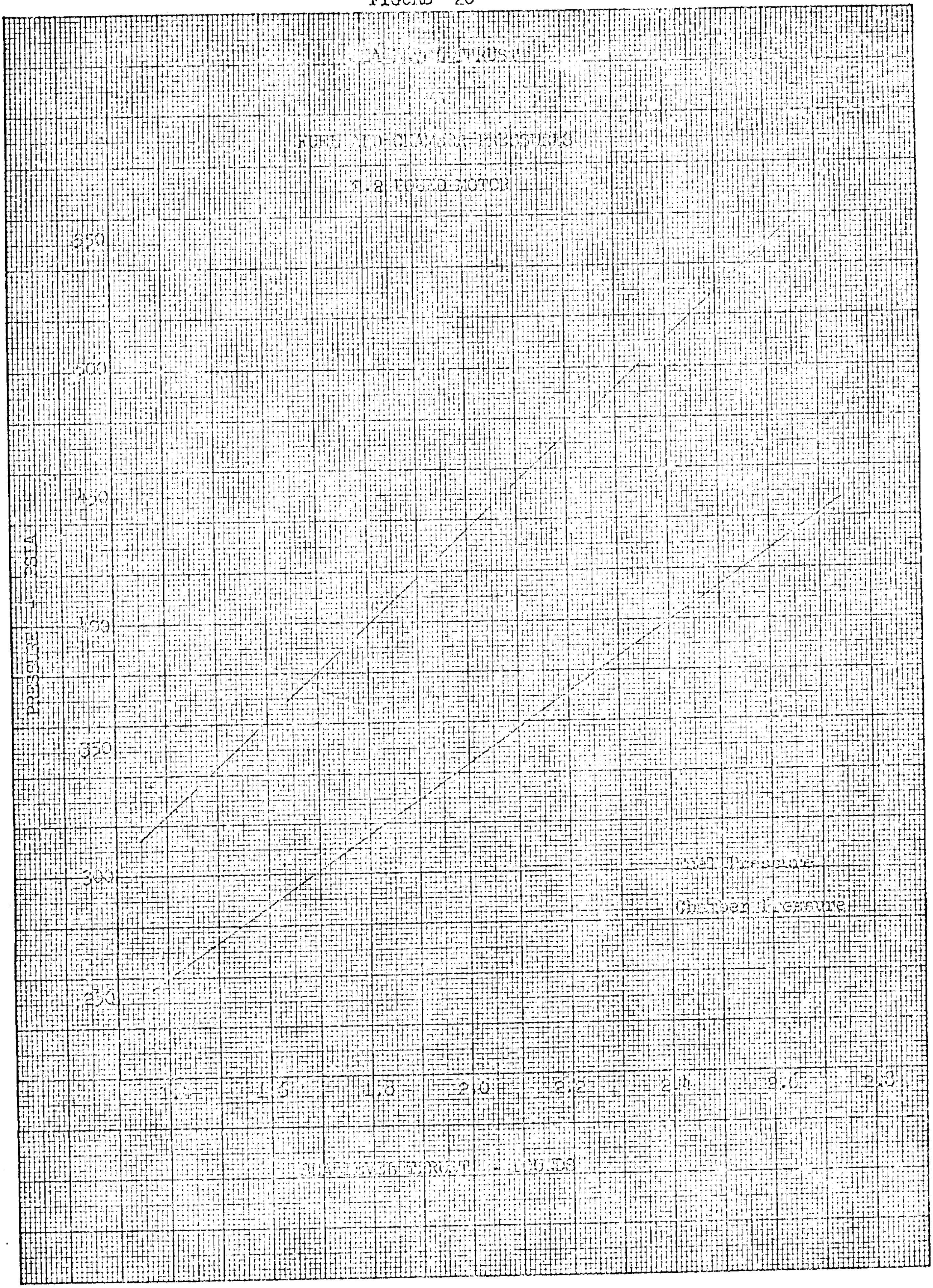

PRESSURE - PSIA
550
500
450
400
350
300
250
2.0
2.2
Chamber Pressure

FIGURE 21

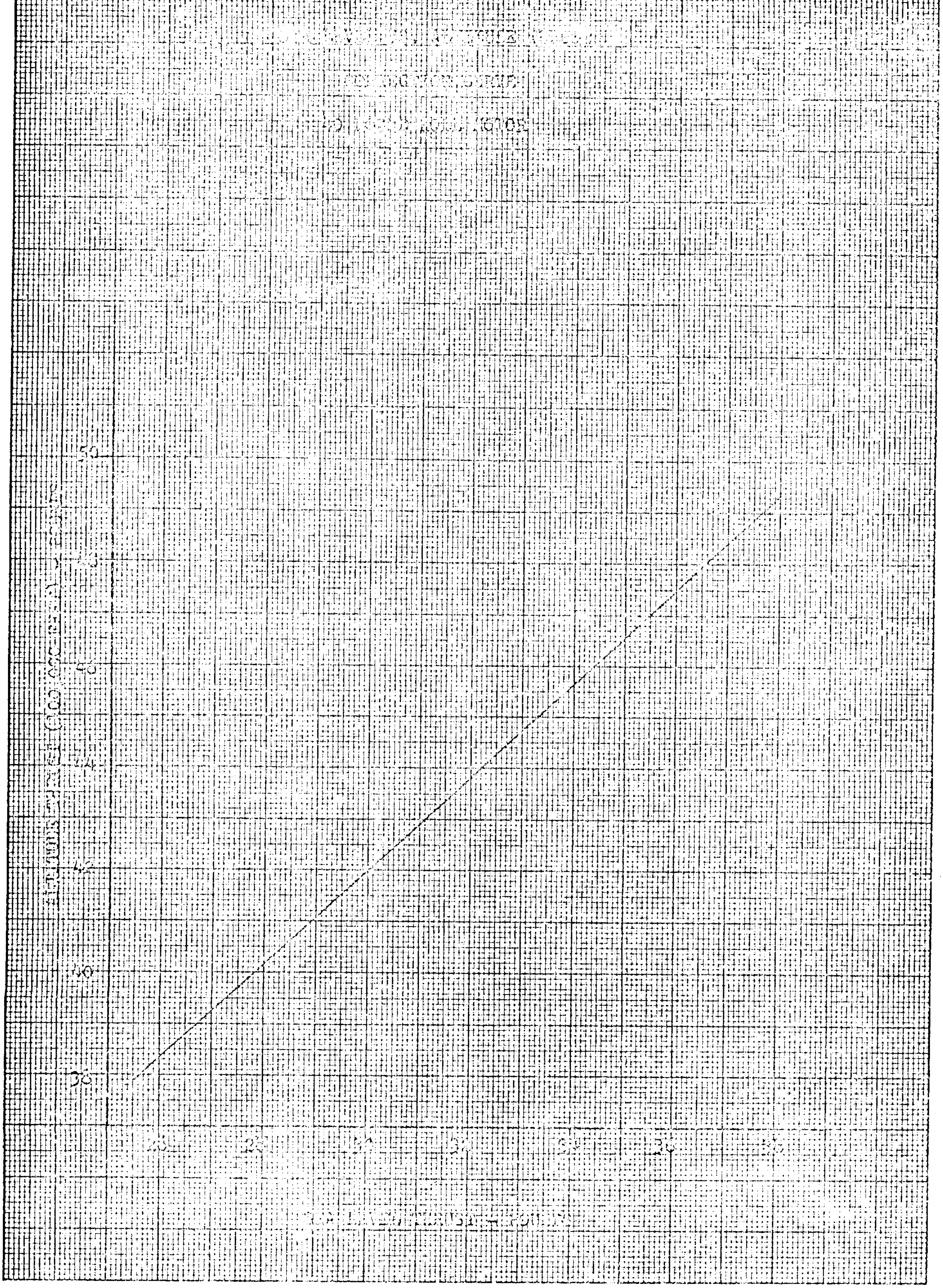
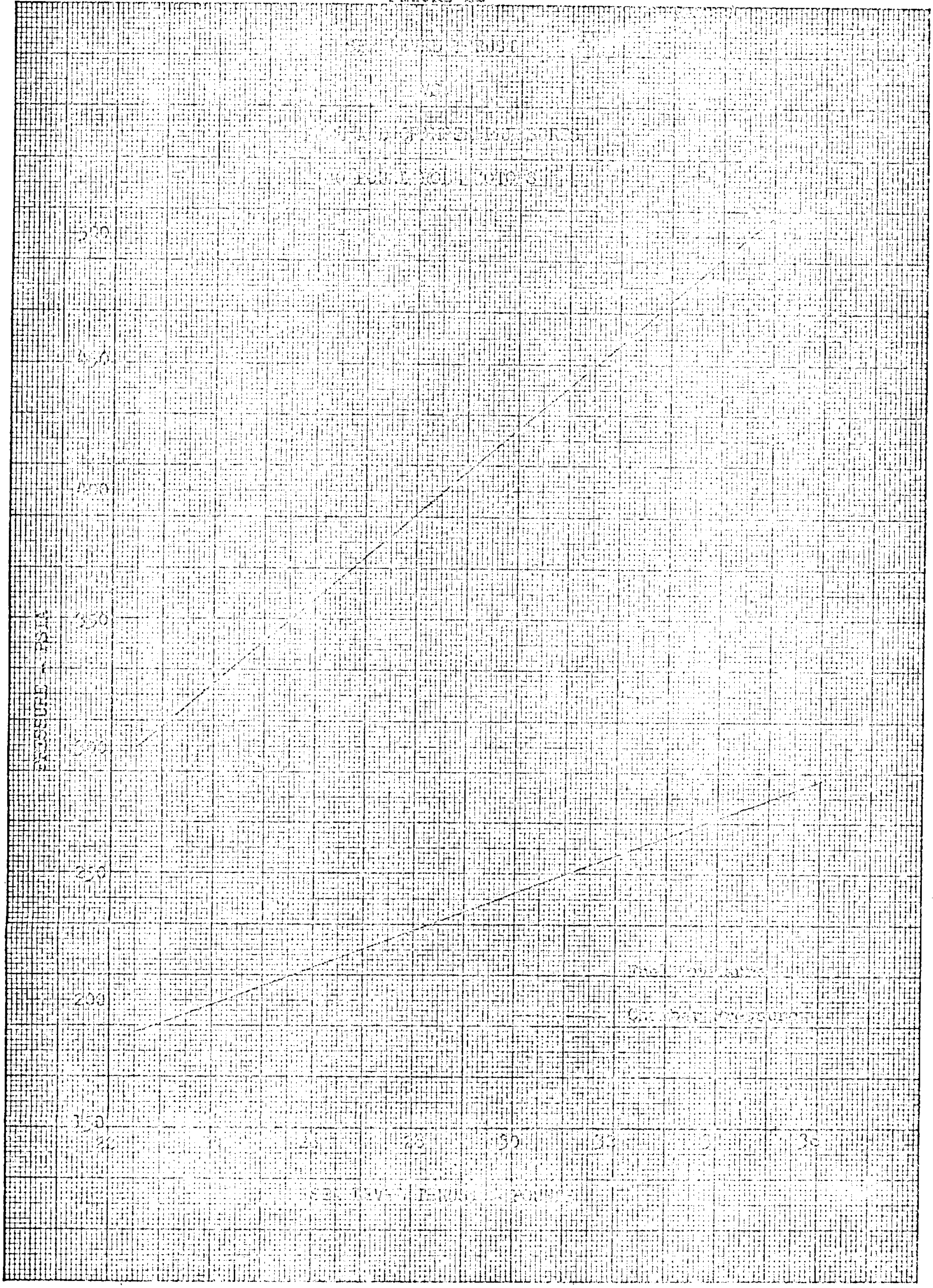


FIGURE 22



APPENDIX

PROPERTIES OF 90 PERCENT HYDROGEN PEROXIDE*

Concentrated hydrogen peroxide has received a relatively wide usage both as the oxidizer component of bi-propellants and as a monopropellant. As a consequence, its properties, both physical and chemical, have been established and materials of construction and procedures of handling have been described. Military Specification MIL-H-16005C amended, covers the procurement of hydrogen peroxide which is to be used for military applications. Some of the physical properties of 90 percent hydrogen peroxide and its decomposition products are presented in the following tables:

Physical Properties of 90 Percent Hydrogen Peroxide

Boiling Point (1 atmosphere)	286.1°F
Density - liquid (77°F)	86.9 lb/cu. ft.
Electrical Conductivity (1 atmosphere)	1.94×10^{-6} ohms/cm.
Freezing Point (1 atmosphere)	11.3°F (Note: contracts 11% in freezing)
Heat Capacity - Liquid (32 to 81°F)	0.660 BTU/lb. - °F
Heat of Decomposition (77°F)	1108.6 BTU/lb.
Heat of Vaporization (80.4°F)	698 BTU/lb.
Molecular Weight (average)	31.2
Surface Tension (68°F)	79.3 Dynes/cm.
Vapor Pressure (70°F)	2.60 mm of Hg
(150°F)	36.3 mm of Hg
Viscosity (77°F)	1.155 Centipoise

*Reference: Becco Bulletins listed in Section 8 of this report.

Properties of 90 Percent Hydrogen Peroxide*

Physical Properties of Decomposition Products of 90 Percent Hydrogen Peroxide

Wt. % of H_2O	57.7
Wt. % of O_2	42.3
Molecular Weight (average)	22.10
C_p	9.47 BTU/mol. °F
C_v	7.48 BTU/mol. °F
C_p/C_v	1.266

Hydrogen peroxide solutions of high purity are very stable. The decomposition of hydrogen peroxide is a strongly exothermic reaction. In spite of this fact, the rate of decomposition is very low in the absence of catalysts. Hydrogen peroxide is remarkable for the number and variety of decomposition catalysts and for the minute quantities required to give large effects. Many, but not all, heavy metals are active decomposition catalysts. Almost all varieties of dust and dirt will catalyze the decomposition of hydrogen peroxide. Hydrogen peroxide solutions are generally more stable when acid and less stable when made alkaline. Acids are, probably, the only known materials which actually increase the stability of hydrogen peroxide.

Stability of Hydrogen Peroxide at Various Temperatures
(Reference: Becco Bulletin No. 46)

Temperatures	Approx. Rate of Decomposition
30°C (86°F)	1% per year
66°C (151°F)	1% per week
100°C (212°F)	Less than 2% per hour
141°C (285°F)	Decompose rapidly with boiling

Hydrogen peroxide decomposition is an exothermic reaction as follows:

$$H_2O_2\ (l) \rightarrow H_2O\ (l) + 1/2\ O_2\ (g) + 23{,}450\ \text{cal.}$$

Upon complete decomposition, 1 liter of 90 percent hydrogen peroxide yields 589 grams of oxygen gas and 801 grams of steam. Under adiabatic conditions, the calculated temperature of these products is 750°C, and their calculated volume is 5000 liters at this temperature and 1 atmosphere. This system has obvious advantages as a power source.

Concentrated hydrogen peroxide has obtained a somewhat exaggerated reputation for being hazardous. Like any material of high energy content, it requires care in handling, but given this care, it can be used in safety.

Hydrogen peroxide solutions and vapors are non-toxic. Both are irritating, however. The vapor causes discomfort of the eyes and nose. The liquid at moderate concentration causes whitening of the skin and a more or less severe stinging sensation. Highly concentrated hydrogen peroxide can cause blistering if left on skin surfaces for any length of time. Contact with the material should be avoided, but immediate flushing with water will prevent any reaction in case accidental contact occurs.

Hydrogen peroxide of high concentration can cause fire upon contact with combustible material. Solutions stronger than about 65 percent can release enough energy to heat the decomposition products to high temperature, i.e., 750°C in the case of 90 percent hydrogen peroxide. Ignition of nearby flammable material is then to be expected. In case of spillage or any other emergency with concentrated hydrogen peroxide, water is the best remedy. If used in time, it will prevent any vigorous reaction, and it is also the best extinguishing agent for fires resulting from spillage.

Apparently, it is impossible to obtain a propagating detonation in pure 90 percent hydrogen peroxide. The material has been subjected to numerous and varied tests and in no case has a propagating detonation been observed.

Catalytic decomposition of hydrogen peroxide in a closed container may cause pressure rupture of the vessel. Containers for hydrogen peroxide should always be vented in order to obviate this possibility.

The first and most important consideration in choosing or designing equipment for H_2O_2 service is that of materials selection. It is essential that all parts of the apparatus which will be exposed to the H_2O_2 be made of sufficiently compatible materials. Extensive tests have been made to determine which materials should be used. The decision as to the compatibility of a certain material is usually based on the following factors:

1. The effect of the material on the rate of decomposition of the H_2O_2.

2. The effect of the H_2O_2 on the materials.

3. The possibility of forming detonable mixtures with H_2O_2.

In choosing metals to be used in contact with hydrogen peroxide, it is necessary to select only those which do not promote decomposition and to avoid dissimilar metals because of the possibility of electrolytic corrosion. The selection criteria for gaskets and lubricants are different. Here, the primary attention is not so much a matter of the materials' catalytic properties, but rather one of avoiding those materials which are easily oxidized or which may react to form sensitive explosive organic peroxides. Suitable materials of this kind are unfortunately limited to the fluorocarbon polymers and polyethylene.

The selection of materials which come in contact with hydrogen peroxide decomposition products on the other hand is, comparatively speaking, less stringent. Here, the main attention is only one of deterioration resistance to oxidation by molecular oxygen at the prevailing temperature.

When deciding which materials should be used for a particular item of equipment, the end use of the item must be a dominant factor. For example, a long-time storage tank should be made of highly compatible material, whereas a valve in a one-shot rocket could be made of less compatible material. Materials have been divided into four general classifications depending on their end use; the table following lists the materials which may be used in hydrogen peroxide service.

Classification of Materials for Use With
90 Percent Hydrogen Peroxide

MATERIAL TYPES	USE CLASSIFICATION 1.	2.	3.	4.
Metals				
Aluminum - 99.6% pure	x	x	x	
2S Alloy	x	x	x	
43		x	x	
52S		x	x	
56S		x	x	
61S		x	x	
63S		x	x	
72S	x	x	x	
75S				x
105S		x	x	
24S				x
13				x
40E				x
Cadmium				x
Chromium				x
Copper				x
Lead				x
Iron or Carbon Steel				x
Nickel				x
Silver				x
Tantalum	x	x	x	
Tin		x	x	
Titanium				x
Zirconium	x	x	x	
300 Series Stainless Steel		x	x	
400 Series Stainless Steel				x

MATERIAL TYPES	USE CLASSIFICATION			
Sealants	1.	2.	3.	4.
Polyethylene	x	x	x	
Teflon	x	x	x	
Kel-F	x	x	x	
Bung Sand N				x
Geon 8372				x
Hycar				x
Koroseal		x	x	
Neoprene				x
Nylon				x
Polystyrene		x	x	
Silicone Rubber			x	
Thiokol				x
Trithene	x	x	x	
Tygon 2807				x
Vinylite		x	x	
Veloform		x	x	
Gatke Moulde Fabric	x	x	x	
Garlock Packing 5681		x	x	
Mylar A and B	x	x	x	
Resistoflex				x
Lubricants				
Aroclors				x
Fluorolubes	x	x	x	
Kel-Flo Polymer Oils	x	x	x	
Perfluorolube Grease and Oils	x	x	x	
Silicones				x
Paraftin Oils and Greases				x
H2 - Hydraulic Fluid		x	x	
Ucon Hydrolube U4				x
Skydrol				x
Halocarbons		x		

Note

Class 1 - Materials are satisfactory for long periods of contact such as in storage tanks and filled lines.

Class 2 - Materials are satisfactory for short time contact prior to storage or use. Useful for all applications except storage.

Class 3 - Materials are satisfactory for short time contact prior to immediate use.

Class 4 - Materials are unsatisfactory.

MATERIAL TYPES	USE CLASSIFICATION			
Sealants	1.	2.	3.	4.
Polyethylene	x	x	x	
Teflon	x	x	x	
Kel-F	x	x	x	
Bung Sand N				x
Geon 8372				x
Hycar				x
Koroseal		x	x	
Neoprene				x
Nylon				x
Polystyrene		x	x	
Silicone Rubber			x	
Thiokol				x
Trithene	x	x	x	
Tygon 2807				x
Vinylite		x	x	
Veloform		x	x	
Gatke Moulde Fabric	x	x	x	
Garlock Packing 5681		x	x	
Mylar A and B	x	x	x	
Resistoflex				x
Lubricants				
Aroclors				x
Fluorolubes	x	x	x	
Kel-Flo Polymer Oils	x	x	x	
Perfluorolube Grease and Oils	x	x	x	
Silicones				x
Paraftin Oils and Greases				x
H2 - Hydraulic Fluid		x	x	
Ucon Hydrolube U4				x
Skydrol				x
Halocarbons		x		

Note

Class 1 - Materials are satisfactory for long periods of contact such as in storage tanks and filled lines.

Class 2 - Materials are satisfactory for short time contact prior to storage or use. Useful for all applications except storage.

Class 3 - Materials are satisfactory for short time contact prior to immediate use.

Class 4 - Materials are unsatisfactory.